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CHARLES F. MARVIN, Chief

# MONTHLY WEATHER REVIEW

VOLUME 48, No. 5

## MAY, 1920

WASHINGTON
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1920

## INTRODUCTION.

The MONTHLY WEATHER REVIEW contains (1) meteorological contributions, and bibliography including seismology; (2) an interpretative summary and charts of the weather of the month in the United States and on the adjacent oceans; and (3) climatological and seismological tables, dealing with the weather and earthquakes of the month.

The contributions are principally as follows: (*a*) Results of the observational or research work in meteorology carried on in the United States or other parts of the world, in the Weather Bureau, at universities, at research institutes, or by individuals; (*b*) abstracts or reviews of important meteorological papers and books, and (*c*) notes. In each issue of the REVIEW reviews, abstracts, and notes are grouped by subjects, roughly, in the following order: General works, observations and reductions, physical properties of the atmosphere, temperature, pressure, wind, moisture, weather; applications of meteorology, climatology, and seismology.

The Weather Bureau desires that the MONTHLY WEATHER REVIEW shall be a medium of publication for contributions within its field, **but the publication of contributions is not to be construed as official approval of the views expressed.**

The partly annotated bibliography of current publications is prepared in the Weather Bureau Library. *Persons or institutions receiving Weather Bureau publications free should send in exchange a copy of anything they may publish bearing upon meteorology, addressed "Library U. S. Weather Bureau, Washington, D. C.,"* in order that the monthly list of current works on meteorology and seismology may be as complete as possible. Similar contributions from others will be welcome. Bibliographies of selected subjects are published from time to time in the REVIEW or SUPPLEMENTS.

The section of the weather of the month contains (1) an interpretative discussion of the weather of North America and adjacent oceans, and some notes on the weather in other parts of the world; (2) details of the weather of the month in the United States; and (3) brief discussions of weather warnings, rivers and floods, and weather and crops. There are illustrative charts. The climatological tables comprise summaries of the weather and excessive precipitation data for about 210 stations in the United States, and summaries of the weather observed at about 30 Canadian stations.

It is hoped that the meteorological data hitherto contributed by numerous independent services will continue as in the past. Our thanks are due especially to the directors and superintendents of the following:

The Meteorological Service of the Dominion of Canada.
Meteorological and Seismological Service of Mexico.
The Meteorological Service of Cuba.
The Meteorological Observatory of Belen College, Habana.
The Government Meteorological Office of Jamaica.
The Meteorological Service of the Azores.
The Meteorological Office, London.
The Danish Meteorological Institute.
The Physical Central Observatory, Petrograd.
The Philippine Weather Bureau.

The seismological tables contain, in a form internationally agreed on, the earthquakes recorded on seismographs in North and Central America. Dispatches on earthquakes felt in all parts of the world are published also.

Since it is important to have as the name of the month appearing on the cover of the REVIEW that of the period covered by the weather discussions and tables rather than that of the month of issue, the REVIEW for a given month does not appear until about the end of the second month following.

SUPPLEMENTS, containing kite observations, and others, containing monographs or specialized groups of papers, are published from time to time.

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## NOTES TO CONTRIBUTORS.

Authors are requested to accompany their papers submitted for publication with a brief opening synopsis. When an article deals with more than one subject—as, for example, a method of measurement—some experimental results and a theory, each subject should be summarized in a *separate paragraph*, with a title which clearly describes it.

When illustrations accompany an article submitted for publication in the MONTHLY WEATHER REVIEW, the places where they should appear in the text should be indicated, and legends or titles for them should be inserted just after the end of the article. As far as practicable the illustrations when accompanied by their legends should be self-explanatory—i. e., the data on them should leave no doubt of what they are intended to convey.

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## BACK NUMBERS OF THE REVIEW WANTED.

As the surplus of MONTHLY WEATHER REVIEW, February, April, June, July, and August, 1919, is exhausted, recipients who do not care to retain their copies will confer a favor by using attached addressed, franked slip. The return of other issues of 1919, 1920, and earlier years will also be appreciated.

# MONTHLY WEATHER REVIEW

CHARLES F. BROOKS, Editor.

VOL. 48, No. 5.
W. B. No. 711.

MAY, 1920.

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## PRELIMINARY STEPS IN THE MAKING OF FREE-AIR PRESSURE AND WIND CHARTS.[1]

By C. LEROY MEISINGER.

[Weather Bureau, Washington, D. C., March 29, 1920.]

SYNOPSIS.

The most accurate forecasts of winds at moderate elevations over wide areas can be made only when we have isobaric and wind charts for those levels. One of the most important steps in the making of such charts is the securing of accurate data on the mean temperature of the air column between the station and a given level in the free air. To this end, such information, obtained by kites at Mount Weather, Va., Drexel, Nebr., and Ellendale, N. Dak., has been classified by months for each of the eight recorded wind directions at the surface. The surface wind direction has been used as an index to determine whether such local phenomena can be used as a guide to conditions aloft. The final values which were obtained from a study of the data represent the differences in degrees, centigrade, between the mean temperature of the air column and the surface temperature. It was found, in general, that in winter, with southerly winds, the air column has a higher mean temperature than the surface; that in summer, with northerly winds, the air column has a temperature below that of the surface. These effects are due, primarily, to the seasonal variation of surface temperature. The amplitude of the values was much greater at the inland stations, Ellendale and Drexel, than at Mount Weather, near the coast. Aside from the geographical contrasts, the difference between the surface temperature and that of the air column to a height of 1 or 2 kilometers depends, so far as the surface factor is concerned, mostly on the season; and, so far as the temperatures aloft are involved, upon the wind direction.

A statistical study of the errors which may be carried into the reductions of pressure to levels in the free air as a result of the errors in the temperature argument, leads to the gratifying result that the values by which the surface temperature is corrected to obtained the mean temperature of the air column, will not, in general, be in error by more than 1.5° C., which, even with long air columns, is not sufficiently large to produce large errors in the pressure. For air columns 1,000 meters in length, when the conditions are, for example, $\theta$=0° C., and $B_0$ (station pressure)=1,000 mb., the study shows that the probable variation of a given value in temperature units will yield a probable variation in pressure units of about ±0.5 mb.; and, under the same conditions, with a 2,000-meter air column about ±1.3 mb. These errors are very small indeed, and give considerable promise to this type of pressure reduction.

### INTRODUCTION.

When Torricelli, in 1643, by his classic experiment,[2] demonstrated that the weight of a given air column is equaled by the weight of a column of mercury of equal cross-section and about 760 millimeters in length, he opened a field of meteorological investigation of such vast extent that even to-day it has not been fully explored. In fact, there are many problems requiring a more satisfactory solution. One of these problems concerns itself with the growing necessity for forecasts of winds aloft for the use of aviation. This problem, emphasized, as it was, by the war, has, with the cessation of hostilities, lost none of its importance, for it is a matter of common comment that the skies are filling with the hum of aerial commercial traffic. The increasing demands for accurate forecasting of conditions aloft necessitate a closer study of these conditions, and an application of what is known, both theoretically and empirically. It is unfortunate, however, that the supply of kite and sounding-balloon data upon which our knowledge rests is, as yet, somewhat limited. While, in general, such forecasting can be done with a certain degree of success by means of the present sea-level isobaric maps supplemented by current aerological data, it is a recognized truth that the promise of best forecasting of winds aloft over wide areas can be found in pressure charts of the same approximate level for which it is desired to forecast.

Not only will the production of accurate maps for upper levels be of value in forecasting for aerial activities, but they will also hold forth the alluring possibility of the solution of one of the long-recognized difficulties in barometry. In 1900 Prof. Bigelow said,[3] concerning this problem:

> The primary practical difficulty in forming station reduction tables for pressure on a plateau or otherwise elevated region consists in determining the mean temperature of the air column to be substituted for the plateau itself, where an observation of temperature can be made only upon the surface of the ground, and the corresponding sea-level temperature can only be indirectly inferred. If the plateau temperature does not agree with that of a free-air column at the same elevation, in what ratio does it differ from it, and how is the difference to be obtained in any exact way that will not be the result of conjecture merely? If the temperature gradients in the free-air can be found by balloon and kite ascensions, or by measurements on cloud heights and by computations on the physical processes involved, how are the corresponding gradients to be found within the plateau itself?

These questions have not been answered, and it is certain that the temperature argument at present employed, i. e., the mean of the current and the preceding 12-hour temperature, often introduces errors in the sea-level reduction, especially where the so-called air column is especially long.

As indicated in the remarks of Prof. Bigelow, the heart of the problem lies in the determination of the mean temperature of the air column, not only in the case where the air column is imaginary, as in sea-level reduction, but also when it is real, as in reduction to levels in the free-air. Realizing this, the scope of this paper is only such as to treat of temperature in relation to pressure reductions in America,[4] through the observations of free-air temperatures by kites and sounding balloons.

### THE VALUE OF FREE-AIR PRESSURE CHARTS.

*Gradient, or geostrophic winds.*—The value of upper air-pressure maps as aids to aviation depends upon the relation between the horizontal air movement and the hori-

[1] Presented in two papers before the American Meteorological Society at St. Louis, Dec. 30, 1919, and at Washington, Apr. 22, 1920.

[2] Hellmann, G.: Neudrucke von Schriften und Karten über Meteorologie und Erdmagnetismus No. 7: *Evangelista Torricelli: Esperienza dell' Argento Vivo.* pp. (1)–(6); and No. 2: *Blaise Pascal: Récit de la Grande Expérience de l'Équilibre des Liqueurs. See also* Zum 250-jährigen Jubiläum des Barometers, *Meteorologische Zeitschrift,* Dec., 1894, pp. 445–450.

[3] Bigelow, Frank H: Report on the barometry of the United States, Canada, and the West Indies. *Report of the Chief of the Weather Bureau,* vol. 2, 1900–1901, p. 25.

[4] The reductions, which were made by Bigelow in the work cited above, employed temperature gradients which were obtained mostly in Europe by manned balloons, temperature distribution in the lowest 5 kilometers of cyclones and anticyclones," and which are not strictly applicable to conditions in the United States. (*See Vertical temperature distribution in the lowest 5 kilometers of cyclones and anticyclones.*" Willis Ray Gregg. MONTHLY WEATHER REVIEW, Sept., 1919, 47: 647–649.)

zontal pressure gradient which produces such movement. It is well known that the surface wind, where it is not influenced too strongly by the terrain, blows at a certain angle across the isobars. This is to be attributed to the rotation of the earth combined with the friction or resistance to the air stream moving over its surface. As we attain even moderate elevations, however, the effect of surface friction is largely eliminated, and the deflection of the air stream by the earth's rotation and the curvature of the isobars are the dominating factors. It is found that at such heights the wind blows practically parallel to the isobars of a given level. This is true, in general, as high as 500 meters, with respect to the sea-level isobars. It should be borne in mind, however, that, strictly, the conduct of the wind at a given level is subject to the pressure distribution at that level. This wind, leaving surface friction out of consideration, is called the gradient, or geostrophic, wind, and may be defined as the wind in which equilibrium is maintained between the pull of gravity down the pressure slope, the deflective tendency due to the earth's rotation, and the centrifugal tendency due to the curvature of the wind path; and its velocity may be computed from the formulæ given by Dr. Humphreys:[5]

$$v=\sqrt{\frac{r}{\rho}\frac{dp}{dn}+(r\omega\sin\phi)^2}-r\omega\sin\phi, \text{ for cyclones;}$$

$$v=r\omega\sin\phi-\sqrt{(r\omega\sin\phi)^2-\frac{r}{\rho}\frac{dp}{dn}}, \text{ for anticyclones;}$$

and,

$$v=\frac{\frac{dp}{dn}}{2\,\omega\rho\sin\phi}, \text{ for straight isobars;}$$

in which $v$ is the velocity, $\frac{dp}{dn}$ is the difference in pressure per unit horizontal distance normal to the isobars; $r=r_1\sec\alpha$, in which $r_1$ is the radius of curvature of the wind path, and $\alpha$ is the angular radius of the circle upon which the air is moving, measured from the center of the earth; $\rho$ is the density of the air, $\omega$ is the angle through which the earth turns in a second, and $\phi$ is the latitude of the place.

The agreement between computed and observed velocities of the wind aloft has often been noted. A good example is to be found in a recent note by Mr. Gregg,[6] in which he computes a wind velocity at 2,500 meters above sea-level of 23 meters per second, a value which agreed within 2 or 3 meters per second with those obtained by many pilot balloon stations in the eastern United States on the days in question. Another example of this relation is given in the flight of free-balloons from Fort Omaha, Nebr., at nearly constant elevations.[7] The first example is one in which the computed wind is obtained from isobars for the 2,500-meter level, whereas the second shows the agreement, up to almost 1 kilometer, where the velocity was computed from the sea-level isobars. It is obvious that were there no surface friction, the surface wind would attain gradient velocity, and this is more nearly the case over the ocean than over the land.

*Forecasting for aviation.*—Now, recognizing the close agreement which obtains between theory and observation, it is apparent that if accurate charts of the pressure aloft can be made, it will not only be possible to tell with almost mathematical accuracy what winds are blowing at the time, but also, after some experience, to forecast what changes are to be expected. This is the point of practical contact with forecasting for aviation.

*General forecasting.*—The contact with the general forecasting of weather is not at once so obvious, and the scheme of free-air pressure charts, in combination with surface weather, is one whose practical utility must be established by experience. This is true especially in the eastern United States, where the average elevation of the land above sea level is not very great. In the West, it appears to be a simple and direct step toward accurately representing the pressure distribution. But this is an old problem and its satisfactory solution must follow a careful and painstaking study. It is believed, however, that these charts will lead in the proper direction for the following reasons:

1st. Reduction planes, say at 1 or 2 kilometers above sea-level, will materially shorten the distance through which pressure must be reduced. It can be seen from the accompanying map (fig. 1) that over the eastern part of the United States the air columns would average about 700 and 1,700 meters in length, respectively, whereas an area half as large as that east of the Mississippi has an elevation of more than a kilometer and a half, and in this area the length of the air column would average about 500 meters to either plane. It will be shown later that considerable errors could exist in the mean temperature of so short an air column without materially affecting the reductions through it.

2nd. Abnormal temperatures, due to chinooks, or other less pronounced causes, introduce considerable error in sea-level reductions[8], whereas a reduction to a free-air plane, as will be shown later, will yield a more truthful representation of facts.

3rd. There is a certain uneasiness in using the temperature argument employed at present, because it does not represent in any real sense that which is implied by $\theta$ in the Laplacian formula, namely, *the mean temperature of the air column between the station and a point in the same vertical located in the reduction plane.* When the reduction is to sea-level *there obviously is no air column* and the value substituted is only an arbitrary one, which, under ordinary conditions, happens to suffice. Free-air charts, on the other hand, do have an air column that is real and observable if means are provided for its observation.

## THE NATURE OF THE INVESTIGATION.

*Wind direction as an index to temperatures aloft.*—From the beginning, the idea of practicability has been kept in mind. It seems desirable to discover some means of reduction of such simplicity and directness that its application will not be difficult. Again, it is desirable to find a method which will relate the temperatures aloft to some observable surface phenomenon. Of all surface phenomena, the one which is most likely to affect temperature, either aloft or at the surface, is wind direction. Will it not be possible from a suitable study of the data to note the wind direction at the surface and the current surface temperature, and, from the time of day and year, tell what correction must be applied to this surface temperature to yield the mean temperature of the air column? It is the answer to this question which it is the immediate purpose of this paper to seek.

[5] Humphreys, William J.: The physics of the air. *Journal of the Franklin Institute*, Nov., 1917, pp. 668–669.

[6] Gregg, Willis Ray: Note on high free-air wind velocities observed December 16 and 17, 1919. MONTHLY WEATHER REVIEW, Dec., 1919, 47: 853–854.

[7] Meisinger, C. LeRoy: The constant elevation free-balloon flights from Fort Omaha. MONTHLY WEATHER REVIEW, Aug., 1919, 47: 535–538

[8] Hallenbeck, Cleve: The influence of abnormal temperature conditions on the sea-level pressure reductions. (Unpublished.) "The writer * * * has observed 'chinook' rises in temperature that lowered the sea-level pressure 0.13 to 0.20 inch, all without affecting the station pressure."

*Aerological observations in the United States.*—In June, 1907, the United States Weather Bureau began making aerological observations at Mount Weather, Va. This was continued for a period of five years, during which time numerous kite and captive balloon ascensions were made for observing conditions aloft. Late in 1915 kite observations were begun at Drexel, Nebr., and since that time flights have been made there almost daily. Still later other stations were established at Ellendale, N. Dak., Broken Arrow, Okla., Groesbeck, Tex., Royal Center, Ind., and Leesburg, Ga. The data from all of these stations have been published [9] and are being published as rapidly as funds will permit. The three stations having the most complete data were selected and investigated, namely, Mount Weather, Drexel, and Ellendale. From these three stations records of over 3,000 kite flights have been examined.

*The selection of reduction levels.*—The question of the selection of reduction levels is an important one, and is, doubtless, one which experience must decide. At the outset, however, there are two considerations which will assist in their tentative selection: First, the level must be sufficiently elevated to be unaffected by topography; and, second, it must be near enough to the surface to represent the pressure distribution which is, at the moment, controlling the surface weather. The elevations of such levels, therefore, depends largely upon the elevation of the surface they are to cover—in other words, upon the general topography of the United States. Fig. 1 shows the general elevations of the United States, with the area above and below each succeeding 500-meter level from sea level to 2 kilometers. The western part of the United States is quite high, many points lying far above the 2-kilometer level. It is thought best, therefore, to investigate temperatures between the surface and the two levels, 1 and 2 kilometers above sea level, respectively.

The elevations of the stations investigated are:

| | Meters above M. S. L. |
|---|---|
| Mount Weather, Va. | 526 |
| Drexel, Nebr. | 396 |
| Ellendale, N. Dak. | 444 |

The first of these stations is located on the Blue Ridge and is situated upon a mountain top, with a valley on either side; the last two are in the open plains region and are well exposed to winds from every direction.

Briefly, then, the procedure of the investigation was as follows: The observed mean temperatures of the air column between the 1 and 2 kilometer levels were tabulated from kite records. The differences between these values and the current surface temperatures were obtained. These differences were then classified by wind directions and months. It must be emphasized that the values to be discussed in this paper are not mean temperatures of the air column, but are *the differences between the mean temperature of the air column and the current surface temperature under certain conditions of wind direction and season.*

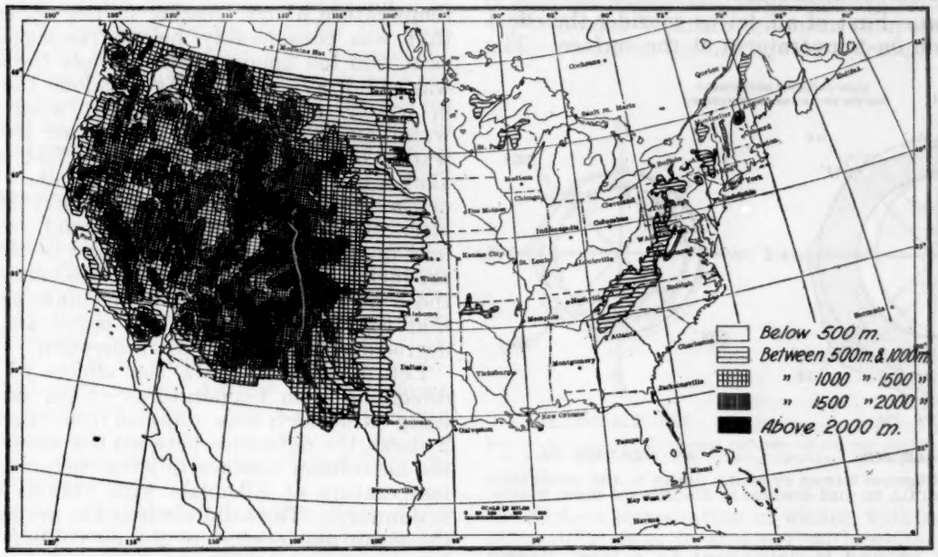



FIG. 1.—Elevations of different portions of the United States above sea-level.

It should further be noted that the kite flights from which these data were obtained were made in the forenoons, and that the average time of the middle of the flights is about 8 a. m. This is because most of the flights at aerological stations are made during the mornings, thus leaving insufficient information from those few which are made in the afternoons. Thus, the values we shall obtain are applicable only to morning conditions, approximately corresponding to the time of regular station observations.

## TEMPERATURES AT THE SURFACE AND ALOFT.

*The factors affecting temperature.*—Temperatures at the surface and aloft may be said to be subject principally to six factors, namely:

1. Wind direction.
2. Seasonal variation.
3. Geographical location.
4. Diurnal variation.
5. State of weather.
6. Character of surface.

[9] Mount Weather: *Bulletin of the Mount Weather Observatory*, vols. 1-6, 1908-1913.
Drexel, Nebr.: MONTHLY WEATHER REVIEW SUPPLEMENTS Nos. 3, 5, 7, 8, 10, 11, 12, 13, 14.
Ellendale, N. Dak.: MONTHLY WEATHER REVIEW SUPPLEMENTS Nos. 12, 13, 14.
Broken Arrow, Okla., and Royal Center, Ind.: MONTHLY WEATHER REVIEW SUPPLEMENTS Nos. 14 and 15.
Groesbeck, Tex., and Leesburg, Ga.: MONTHLY WEATHER REVIEW SUPPLEMENT No. 15.

Winds aloft and surface winds may be affected in greater or less degree by each of these factors, and these relations and interrelations will be discussed. It is possible at the outset, however, to eliminate the last three factors from consideration in this discussion. While it is obvious that temperatures may vary considerably, especially at the surface, during the daily period, such variation is not important in this discussion, since all observations were made at practically the same time of day at all stations. Second, the conditions of the cloudiness of the sky may exert a less marked influence upon temperatures; but, in this work, all the observations have been lumped together, whether made in clear, partly cloudy, or cloudy sky; hence the averages represent the means of conditions with all degrees of cloudiness. Finally, the character of the surface need not be considered, since all the observations have been made over land surfaces which are, in the main, of the same character. The only exception is that in the case of Mount Weather, whose mountain location was taken into consideration, as will be shown. This leaves the first three factors to be considered.

*Wind direction.*—First of all, let us consider the effect of wind direction on temperatures at the surface. The

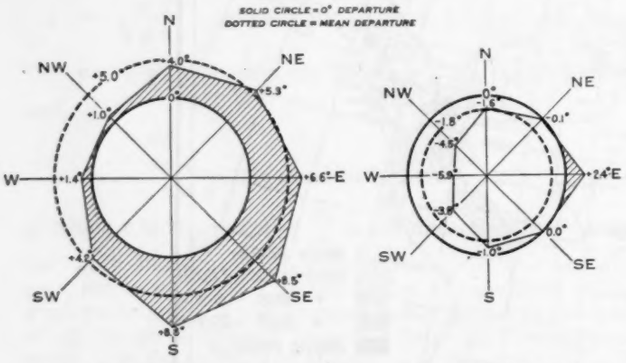



FIG. 2.—Temperature differences between air column (surface to 2,000 meters above sea-level) and surface (°C.), by wind directions for Ellendale and Mount Weather, in January.

air next to the ground is dependent to a large degree upon the temperature of the surface itself. If it be warm, as in summer, and the wind becomes northerly, and the air of relatively low temperature transported to regions where the earth is very warm, it is well known that the wind must be persistent in order to affect to any considerable degree the temperature of the region; for the high temperature of the earth will warm the air [10] as it progresses southward. There are many familiar examples of southerly winds in winter, blowing out of very warm regions and losing their identity as warm winds after blowing over cold ground or snow-covered surface for some distance. True, if the winds are of high velocity and persist for a considerable time, they will have a telling effect upon surface temperature. This, of course, does not refer to such abnormal local effects as chinooks, in which winds with a temperature far higher than that of the surface, owing to dynamic heating, suddenly swoop down upon a locality, often with sufficient effectiveness to melt and evaporate entirely a considerable depth of snow without leaving so much as a muddy surface;[11] nor are we referring to cases in which a very warm layer of air may be overriding a cold one in waves in such a manner that the troughs of the waves may occasionally intersect the surface, and produce for a short time a change of wind direction and an abnormally high temperature. We have reference, rather, to the normal varying circulation about the ordinary veering and backing of winds as the result of the passage of HIGHS and LOWS.

But what of the temperatures aloft? They are not subject to the effects of radiation and absorption of the earth's surface to the same degree as are surface temperatures. The frictional turbulence of the lower layers does not play so conspicuous a part in the determination of temperatures aloft. They are dependent upon the temperature of the region from which the air is being transported. If from the south in winter, an upper current may retain its identity as a warm one over others many degrees colder. As an example of this, one may note the upper air phenomena which accompanied the recent sleet storms in eastern United States.[12] Here, the southerly component produced a temperature above freezing in the upper air over land that was considerably below freezing; indeed, in one case, rain fell upon a surface where the air temperature was as low as —11° C. Again, along the Atlantic coast, in winter, an east or southeast wind may transport warm air from the Gulf stream or from the warmer waters of the Atlantic, but the effect is most marked aloft. Or, in the plains States, winds which have their origin in the chinooks of the Rocky Mountains, may, after striking the surface, rebound, as it were, and flow out over the cold air blanket of the Middle West, producing upper-air temperatures much higher than those at the surface.[13] These points seem to indicate that the temperatures of the upper air are to a great degree dependent upon wind direction.

Let us now compare the effects of different wind directions upon temperatures at the surface and aloft, using data which were obtained from kite flights. Figure 2 shows the difference between the mean temperature of the air column (surface to 2,000 meters) and the surface temperature at Ellendale with various wind directions in January. The solid circle is the origin or locus where the mean temperature of the air column equals the surface temperature. The actual values are measured from this circle along radii which represent wind directions, and, if positive, are measured outward; if negative, inward. A study of this diagram will show several features of interest which will be pointed out from time to time. But the significant point in the present connection is that westerly or northwesterly winds produced aloft the lowest temperatures relative to those at the surface, while southerly or southeasterly winds produced aloft the highest temperatures relative to those at the surface. The fact that all the values for January at Ellendale are positive will be brought out later in the discussion. Figure 2, which gives, in the same manner, the data for Mount Weather for January, shows the same effect, except that, owing to its coastal location, westerly winds produce lowest temperatures aloft rela-

[10] Martin, Howard H.: The relation of winds to temperature in Central Ohio. MONTHLY WEATHER REVIEW, February, 1920, 48: 85-86.

[11] Mr. Herbert Lyman, at Helena, Mont., has observed a snow cover of 10 inches disappear over night, leaving a dry surface the following morning. *See also*, Mark W. Harrington: The chinook winds. *American Meteorological Journal*, vol. 3, pp. 520-521, 1887.

[12] Meisinger, C. LeRoy: The precipitation of sleet and the formation of glaze in eastern United States, with remarks on forecasting. MONTHLY WEATHER REVIEW, Feb., 1920, 48: 73-80.

[13] Bavendick, F. J.: Blizzards and chinooks of North Dakota plains. MONTHLY WEATHER REVIEW, Feb., 1920, 48: 82-83.

tive to the surface, while easterly winds, blowing off the ocean, produce highest relative temperatures aloft.

It is necessary to digress, for a moment, to mention that, owing to the mountain-top location of Mount Weather, the surface temperatures employed are those of the nearest Weather Bureau station in the valley, namely, Washington, D. C., about 40 miles southeast of the mountain. In determining the mean temperature of the air column, the mean was taken between the Washington surface and the Mount Weather surface, which gave a good value for the mean temperature of the lowest 500 meters. Above Mount Weather the kite results are used and these are averaged with the previously determined value for the lowest 500 meters. Hence, in the strictest sense, these are the mean temperatures above Washington, D. C., although if this fact is borne in mind, there should be no confusion in referring to Mount Weather data.

Figure 3 shows the same effects as were pointed out above, but to a much smaller degree, the reason being that the seasonal effect is of so much greater amplitude that the effect of wind direction is nearly obliterated in summer. Figure 4, however, brings together the data for all the stations for the whole year and contrasts the effect of two opposing winds upon the difference between the mean temperature of the air column and the surface temperature. Let us, in considering this diagram, try to neglect the annual march of these temperature differences and think only of the comparison between the two wind directions for a given station. First, consider Ellendale: With a southeast wind we find nearly all the ordinates are positive in sign indicating that the mean temperature of the air column is greater than the surface temperature. With a northwest wind most of the ordinates are negative. For Drexel, the mean ordinate is somewhat less than that of Ellendale, but has the same general characteristics, namely, that its mean ordinate for a southeast wind is greater by several degrees than the mean ordinate with a northwest wind. Similarly, for Mount Weather all values are negative for both winds, the southeast giving a mean ordinate approximately 3° C. higher than the northwest.

*Seasonal variation.*—Considering next the effect of seasonal change of temperature upon the surface and upper levels, we know from experience that the seasonal amplitude of the temperature march is large. We have only to reflect upon the contrast between the blistering days of midsummer and the raw, biting blasts of midwinter, to convince ourselves of the truth of this statement. Aloft, on the other hand, the amplitude is not so great. An excellent illustration of this is given by Mr. Gregg for Drexel, Nebr.[14] He shows in a diagram the annual march of temperature at the surface and at levels in the free air. At the surface we find a variation of 36° C., from a minimum of −9° C. in mid-January to +27° C. in mid-July. At 1 kilometer above sea level the values extend from a minimum of −8° C. in January to +22° C. in July, or a range of 30° C. At 2 kilometers the range is from −7° C. to +16° C., or a range of 23° C. This shows that as one ascends and frees oneself from the surface influence, the amplitude of seasonal variation becomes smaller and smaller.

With these facts in mind, we can consider our diagrams in the light of seasonal variation. Turning again to figure 2. For Ellendale, located in the heart of the continent and in a northerly latitude, we know that not only is the annual march of temperature of great amplitude, but also that the tendency is for extremely cold winters. The diagram shows that all wind directions give a temperature aloft which is higher than that at the surface. In July (fig. 3) we find that the temperatures aloft are lower than at the surface. But we know that the annual range aloft is less than at the surface. Hence we must attribute the great difference between the values with a given wind direction in January and July to the seasonal range of surface temperature. The same is true at Mount Weather (figs. 2 and 3). In January we find the values much higher than the corresponding values in July. The reason, of course, is that we have superimposed upon a widely varying range of surface temperatures a lesser range aloft.

For the entire year, we see from figure 4 that for all stations there is a decided maximum in winter and a minimum in summer, indicating that in summer the air aloft at Ellendale and Drexel tends to have, with southerly winds, large positive values and in winter small negative values; with northerly winds in winter small positive values, and in summer moderately large negative values.

For Mount Weather the mean temperature of the air column tends to become equal to, or slightly higher than,

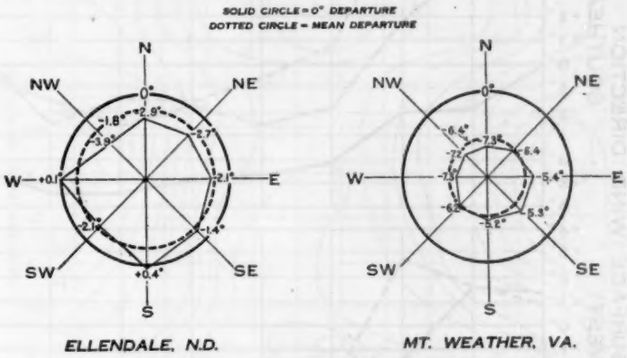



FIG. 3.—Temperature differences between air column (surface to 2,000 meters above sea-level) and surface (°C.), by wind directions for Ellendale and Mount Weather, in July.

the surface temperature in winter, with rather large negative differences in summer with southerly winds, and with northerly winds to have a more uniform negative difference throughout the year.

*Geographical location.*—The relation of wind direction and seasonal variation to temperatures, both at the surface and aloft, has been mentioned. Now, let us examine the effect of geographical location. First, we know that inland locations, as characterized by Ellendale and Drexel, have greater extremes of temperature than those coastal stations of which Mount Weather is an example. This is due, of course, to the location with respect to the ocean with its moderating influence. Land, being a better absorber and radiator of heat than water, will heat up more rapidly in summer and cool more rapidly in winter than will the ocean. By way of comparison with the value of surface temperature and temperatures in the free air, similar to that of Drexel, we have for Mount Weather [15] a maximum mean surface temperature of 23° C. and a mean minimum of −1° C., a range of 24° C. At 1,000 meters above sea level we have a mean maximum of 19° C. and a mean minimum of −2° C., a range of 21° C.; and at 2,000 meters there is a mean maximum

[14] Gregg, Willis Ray. Average free-air conditions as observed by means of kites at Drexel Aerological Station, Nebr., during the period November, 1915, to December 1918, inclusive. MONTHLY WEATHER REVIEW, January, 1920, 48: 1-11.

[15] Blair, William R.: Summary of the free-air data obtained at Mount Weather for the five years, July 1, 1907, to June 30, 1912. *Bulletin of the Mount Weather Observatory*, vol. 6, 1913, p. 179.

of about 13° C., and a mean minimum of about −4° C., giving a range of 17° C. In Table 1 these values are contrasted with those of Drexel.

TABLE 1.

| Station. | Surface. | | | 1 kilometer. | | | 2 kilometers. | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Range. | Max. | Min. | Range. | Max. | Min. | Range. |
| | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. | °C. |
| Drexel, Nebr. | 27 | −9 | 36 | 22 | −8 | 30 | 16 | −7 | 23 |
| (Washington, D. C.) | (30) | (−3) | (33) | | | | | | |
| Mount Weather | 23 | −1 | 24 | 19 | −2 | 21 | 13 | −4 | 17 |

Thus, comparing inland and coastal temperatures for the surface, we find that the inland surface experiences the larger range; in this case, 3° C. larger; aloft, also, there is a smaller range of temperature near the coast than inland, the differences from the table being, for the 1-kilometer level, 9 °C., and for the 2-kilometer level, 6 °C.

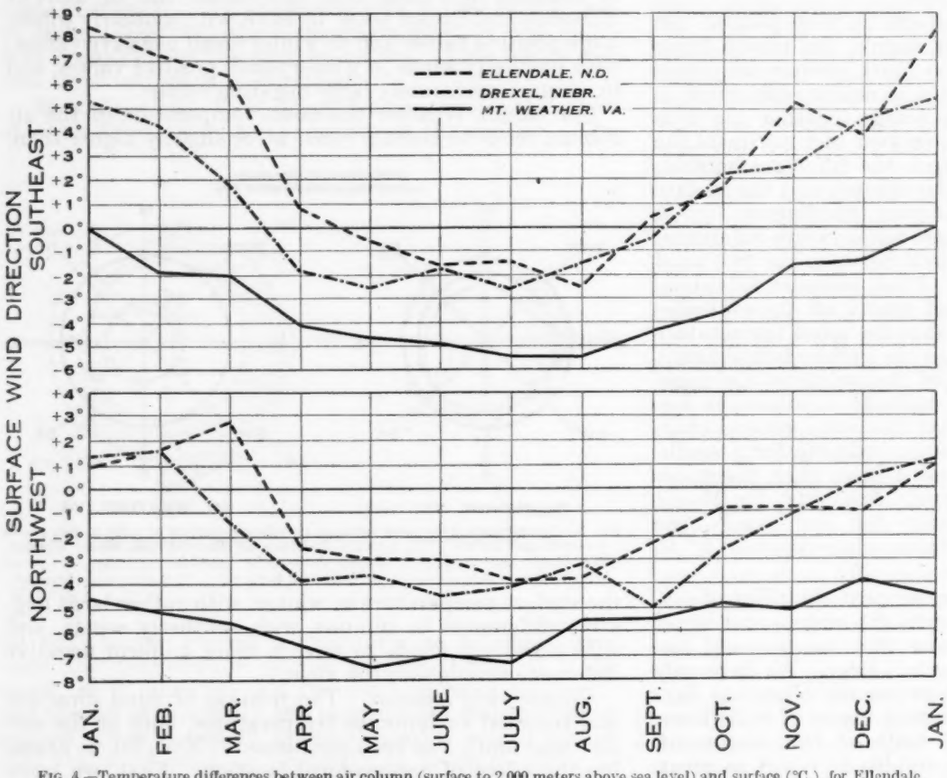



FIG. 4.—Temperature differences between air column (surface to 2,000 meters above sea level) and surface (°C.), for Ellendale, Drexel, and Mount Weather, for southeast and northwest winds, throughout the year.

Referring again to figure 4, we see that the inland stations are those of greatest amplitude. The curve for Mount Weather is relatively flat. This means that the temperature differences at the surface, attributable to the geographical distribution of the stations is reflected in the temperatures aloft, but to a less marked extent.

*Summary of the effects of the factors.*—An effort has been made in the foregoing discussion to separate the individual factors from the complex or operative factors in each diagram. But this is difficult, especially where all the factors are simultaneously operative. And in reality each of the diagrams has shown the total or resultant effect of the three factors we have treated above, wind direction, seasonal variation, and geographical location. It is now well to consider the results as we find them in combination. First, concerning surface temperatures, it should be said that they are influenced primarily by seasonal variation and geographical location. Next, temperatures aloft are influenced chiefly by wind direction, but do not respond to seasonal variation or geographical location as easily or completely as do these at the surface. What is the result of this combination?

It means that for winter, at inland stations, there is a strong tendency for air warmer than that at the surface to be present aloft with all directions of surface wind (fig. 2). For summer, at inland stations, there is a strong tendency for air cooler than that at the surface to be present aloft, with all directions of surface wind (fig. 2). For winter, at coastal stations, there is a tendency when the station is on the east coast, for warmer air aloft with east winds, and for cooler air aloft with west winds. For summer, at coastal stations, there is a tendency for cooler air aloft from all directions.

To bring all the information toegther, six diagrams have been prepared which show for each month and for each surface wind direction, the difference between the mean temperature of the air column and the surface temperature for that place, from the surface to 1 kilometer above sea level, and from the surface to 2 kilometers above sea level, respectively. Figures 5 and 6 give this information for Mount Weather; figures 7 and 8 for Drexel, and figures 9 and 10 for Ellendale. The main features of these isopleths are fairly obvious, and have really been pointed out in the foregoing discussion. For instance, all the diagrams show a maximum in winter with southerly winds, except in figure 6, where the maximum occurs with an easterly wind, because of the warm air from the ocean. As we proceed to the inland stations, the amplitude, indicated by the crowding of the isotherms, increases, until for Ellendale (fig. 10) the winter maximum gives a temperature of the air column between the surface and the 2 kilometers level 9° C. higher than the surface temperature. These curves have been smoothed but very little. In each case the 0° departure lines have been drawn heavier than the others.

*An example of the use of the isopleths.*—To be certain that the full value of the isopleths is understood, an example is given: Suppose that at Ellendale on the morning of April 15 we have a surface wind from the west and a temperature of 10° C. What is the mean temperature of the air column between the surface and the 2-kilometer level? Looking at figure 10, we find the point on the chart corresponding to April 15 along the axis of abscissæ, and "west" on the axis of ordinates, and the value of that point obtained by interpolating between the isotherms is −2.2° C. This means that to find the mean temperature of the air column we must subtract

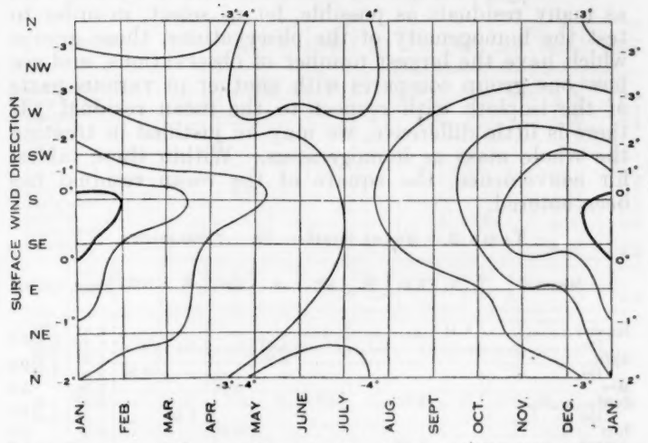



FIG. 5.—Temperature differences between air column (surface to 1,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Mount Weather, Va.

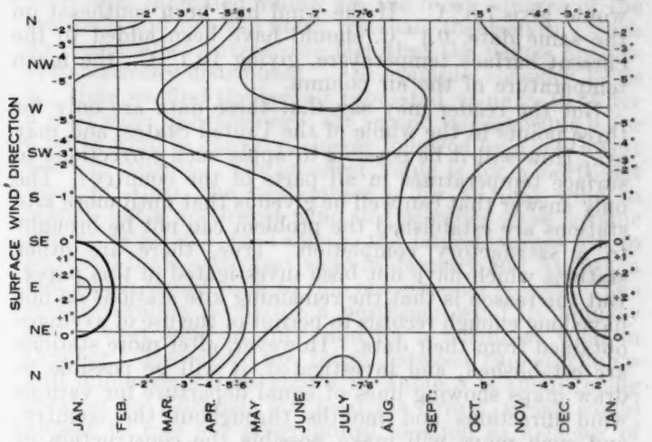



FIG. 6.—Temperature differences between air column (surface to 2,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Mount Weather, Va.

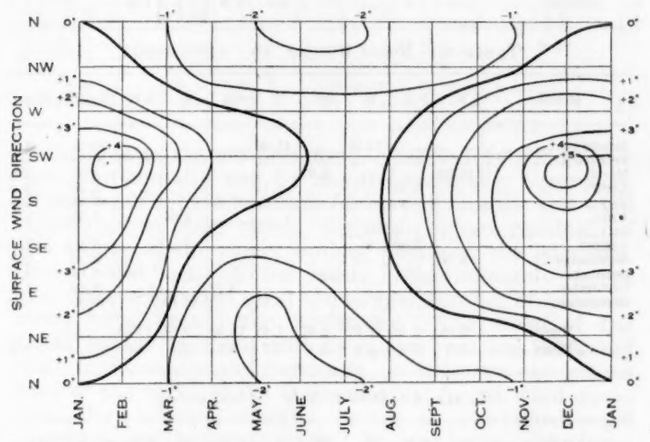



FIG. 7.—Temperature differences between air column (surface to 1,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Drexel, Nebr.

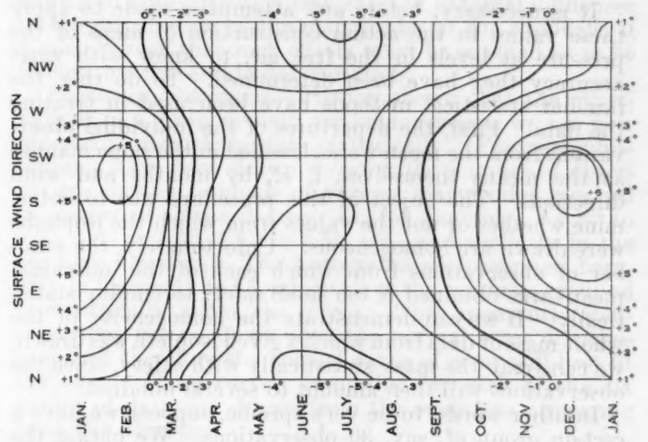



FIG. 8.—Temperature differences between air column (surface to 2,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Drexel, Nebr.

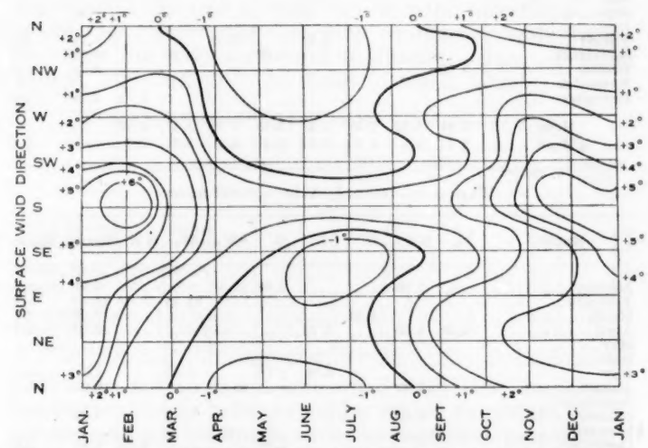



FIG. 9.—Temperature differences between air column (surface to 1,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Ellendale, N. Dak.

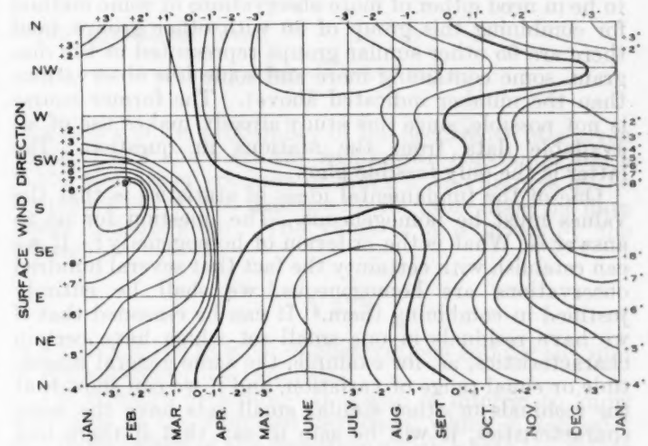



FIG. 10.—Temperature differences between air column (surface to 2,000 meters above sea-level) and surface (°C.), for the eight recorded wind directions throughout the year at Ellendale, N. Dak.

2.2° C. from the current surface temperature, which would give 7.8° C. If the wind had been southeast on the same date, 0.1° C. should have been added to the current surface temperature, giving 10.1° C., the mean temperature of the air column.

But the reader may say that these data are only for three points in the whole of the United States, and may ask, How will it be possible to apply such corrections to surface temperatures in all parts of the country? The only answer that can well be given is that until more kite stations are established the problem can not be brought to a satisfactory completion. True, there are other stations which have not been investigated in this paper. But the reason is that the remaining kite stations do not have long enough records to permit of the use of averages obtained from their data. However, after more stations are established, and investigated, it will be possible to draw maps showing lines of equal departure for various wind directions and months throughout the country, and such maps will make possible the construction of temperature tables for any station.

## THE ACCURACY OF THE VALUES.

It is necessary, before any attempt is made to apply these values to the actual construction of maps of the pressure at levels in the free air, to know with what accuracy they have been determined. To do this, the familiar statistical methods have been used in treating the data. First, the departures of the individual observations from the mean were classified in the same manner as the means themselves, i. e., by months and wind directions. The object of this procedure was to determine whether or not the values from which the isopleths were drawn are homogeneous. Unfortunately, the number of observations from which each of the individual means was obtained is too small safely to employ statistically. If we can demonstrate the homogeneity of the whole mass of data from which a given isopleth was drawn, we can treat the mass statistically with safety, since the observations will then amount to several hundred.

In other words, to be very specific, suppose we have a certain group of, say, 30 observations. We obtain the mean and tabulate the difference between this mean and the 30 individual observations. The mean will represent one of the points on the isopleth, but since 30 is usually too small a number to treat statistically, we seem to be in need either of more observations or some method for combining this group of 30 with other groups (and there are 95 other similar groups represented in the diagram, some containing more and some less observations than the number indicated above). The former course is not possible, since this study already makes use of all available data from the stations in question. The latter is the only feasible plan.

One of the fundamental ideas of statistics is that the values must be homogeneous. The question for us to answer is, What is the criterion of homogeneity? If we can establish with certainty the fact that several hundred observations are homogeneous, we shall be entirely justified in combining them. It can be reasoned that if we have residuals in one small set which have certain characteristics, as, for example, the same general magnitude or equal range of variation, and if we can show that the residuals in other similar small sets have the same characteristics, it will be safe to say that if there had been as many observations in each individual set as the total when they are all combined, the result for each set would be the same as is the result for the entire total now.

*The test for homogeneity.*—For the sake of dealing with as many residuals as possible, let us select, in order to test the homogeneity of the observations, those groups which have the largest number of observations, and see how one group compares with another in various parts of the isopleth with respect to the mean residual. If there is little difference, we may be justified in treating the whole mass as homogeneous. Within these tables, for convenience, the square of the mean residual has been entered.

TABLE 2.—*Mount Weather, Va. 1,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 8.44 | | | | | | | | 8.44 | 2.9 |
| Do | | | | | 8.31 | | | | 8.31 | 2.9 |
| April | | | | | 4.96 | | | | 4.96 | 2.2 |
| Do | | | | | | | | 2.99 | 2.99 | 1.7 |
| May | | | | | | 6.96 | | | 6.96 | 2.6 |
| June | | 3.56 | | | | | | | 3.56 | 1.9 |
| Do | | | | | | | 1.64 | | 1.64 | 1.3 |
| July | | | | | | 0.91 | | | 0.91 | 0.9 |
| August | | 1.39 | | | | | | | 1.39 | 1.2 |
| September | 2.36 | | | | | | | | 2.36 | 1.5 |
| October | | | | | | | | 1.69 | 1.69 | 1.3 |
| November | | | | | | 3.94 | | | 3.94 | 2.0 |
| December | | | | | | | 4.81 | | 4.81 | 2.2 |
| Mean | 5.40 | 2.47 | | | 6.63 | 3.94 | 3.22 | 2.34 | | |
| √Mean | 2.3 | 1.7 | | | 2.6 | 1.9 | 1.9 | 1.6 | | 1.9 |

TABLE 3.—*Mount Weather, Va. 2,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | | | 15.97 | | 11.06 | | | | 13.51 | 3.7 |
| February | | | | | | | | 20.04 | 20.04 | 4.5 |
| March | 10.69 | | | 5.97 | | | | | 8.33 | 2.9 |
| April | | 5.85 | | | 6.11 | | | | 5.98 | 2.4 |
| May | | | | | | 17.83 | | | 17.83 | 4.2 |
| June | | | | | | | 3.39 | | 3.39 | 1.8 |
| July | | | | | | | | | | |
| August | | 3.13 | | | | | | | 3.13 | 1.8 |
| September | 3.20 | | | | | | | | 3.20 | 1.8 |
| October | | | | | | | | 5.02 | 5.02 | 2.2 |
| November | | | | | | 9.19 | | | 9.19 | 3.1 |
| December | | | | | 5.75 | | 15.89 | | 10.82 | 3.3 |
| Mean | 6.94 | 4.49 | 15.97 | 5.97 | 7.64 | 13.51 | 9.64 | 12.53 | | |
| √Mean | 2.6 | 2.1 | 4.0 | 2.4 | 2.7 | 3.7 | 3.1 | 3.5 | | 2.9 |

TABLE 4.—*Drexel, Nebr. 1,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | 11.67 | 2.75 | | | | 9.46 | | 7.25 | 7.78 | 2.8 |
| February | | | | | 7.22 | | | | 7.22 | 2.7 |
| March | | | 2.28 | 7.22 | | | | | 4.75 | 2.2 |
| April | | 1.68 | | | | | 8.49 | | 5.08 | 2.2 |
| May | | | | | | | | | | |
| June | | | | | | | | | | |
| July | | | | | | | | | | |
| August | | | | 3.43 | | 10.99 | | | 6.71 | 2.6 |
| September | | | | | 3.28 | | 18.46 | | 10.87 | 3.3 |
| October | 3.22 | | | | | | | | 3.22 | 1.8 |
| November | | | | | | | | | | |
| December | | | | | | | | 2.74 | 2.74 | 1.6 |
| Mean | 7.44 | 2.22 | 2.28 | 5.33 | 5.25 | 9.72 | 13.47 | 4.99 | | |
| √Mean | 2.7 | 1.5 | 1.5 | 2.3 | 2.3 | 3.1 | 3.7 | 2.2 | | 2.4 |

TABLE 5.—*Drexel, Nebr. 2,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | | 1.90 | | | 5.06 | 13.48 | | | 6.81 | 2.6 |
| February | | | | | | | 12.46 | 10.38 | 11.42 | 3.4 |
| March | | | 4.26 | | | | | | 4.26 | 2.1 |
| April | 5.59 | 4.20 | | 5.22 | | | | | 7.50 | 2.7 |
| May | | | | | | | | | | |
| June | | | | | | | | | | |
| July | | | | 6.93 | 2.78 | | 1.92 | | 5.81 | 2.4 |
| August | | 4.89 | | | | 15.23 | | | 10.06 | 3.2 |
| September | | | | | | | | | | |
| October | | 0.62 | | | | | | | 0.62 | 0.8 |
| November | | | | | | | | | | |
| December | | | | | 7.89 | | | 6.02 | 6.95 | 2.6 |
| Mean | 5.59 | 2.90 | 4.26 | 6.07 | 7.86 | 14.35 | 7.19 | 8.20 | | |
| √Mean | 2.4 | 1.7 | 2.1 | 2.5 | 2.8 | 3.8 | 2.7 | 2.9 | | 2.5 |

TABLE 6.—*Ellendale, N. Dak. 1,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | ..... | ..... | ..... | ..... | ..... | ..... | 7.35 | 4.55 | 5.95 | 2.4 |
| February | 1.82 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1.82 | 1.3 |
| March | ..... | ..... | ..... | ..... | 9.27 | 2.05 | ..... | ..... | 5.66 | 2.4 |
| April | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| May | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| June | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| July | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 4.11 | 4.11 | 2.0 |
| August | ..... | 2.92 | ..... | ..... | ..... | ..... | ..... | ..... | 2.92 | 1.7 |
| September | 1.76 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1.76 | 1.3 |
| October | ..... | ..... | ..... | ..... | ..... | ..... | 1.07 | ..... | 1.07 | 1.0 |
| November | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| December | ..... | ..... | ..... | ..... | 20.35 | ..... | ..... | ..... | 20.35 | 4.5 |
| Mean | 1.79 | 2.92 | ..... | ..... | 14.81 | 2.05 | 4.21 | 4.33 | ..... | ..... |
| √Mean | 1.3 | 1.7 | ..... | ..... | 3.8 | 1.4 | 2.1 | 2.1 | ..... | 2.1 |

TABLE 7.—*Ellendale, N. Dak. 2,000 meters.*

| Month. | N. | NE. | E. | SE. | S. | SW. | W. | NW. | Mean. | √Mean. |
|---|---|---|---|---|---|---|---|---|---|---|
| January | ..... | ..... | ..... | ..... | ..... | ..... | 8.69 | 6.67 | 7.68 | 2.8 |
| February | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| March | 8.73 | ..... | ..... | ..... | 10.90 | 1.68 | ..... | ..... | 7.10 | 2.7 |
| April | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| May | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| June | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| July | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| August | ..... | 7.65 | ..... | 7.82 | ..... | ..... | ..... | ..... | 7.73 | 2.8 |
| September | 3.93 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.93 | 2.0 |
| October | ..... | ..... | ..... | ..... | ..... | ..... | 1.99 | 6.22 | 4.10 | 2.0 |
| November | ..... | ..... | ..... | ..... | ..... | 30.12 | ..... | ..... | 30.12 | 5.5 |
| December | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Mean | 6.33 | 7.65 | ..... | 7.82 | 10.90 | 15.90 | 5.34 | 6.44 | ..... | ..... |
| √Mean | 2.5 | 2.7 | ..... | 2.8 | 3.3 | 4.0 | 2.3 | 2.5 | ..... | 2.9 |

In these tables are presented, classified by wind directions horizontally and by months vertically, the values of the mean square residuals for certain months and wind directions; in other words, the mean square residuals of the values of the corresponding points in the isopleths. These have been selected rather indiscriminately except that values founded upon the largest number of observations have been given preference. The mean of the mean square residuals and its square root are tabulated both horizontally and vertically, so that one can get an idea of the value of the mean residual for all wind directions for different months, or for an individual wind direction for the whole year. In the lower right-hand corner appears for comparison with the other tables the value of the mean of the mean residuals.

A perusal of these tables will convince one that there are no systematic variations in the values of errors throughout the year or with various wind directions. To make this clearer, the following condensed table brings together the maximum and minimum values of these means, together with the mean for each table:

TABLE 8.—*Summary of data on the distribution of errors.*

| | Maximum. | Minimum. | Range. | Mean for table. |
|---|---|---|---|---|
| | °C. | °C. | °C. | °C. |
| Mount Weather, 1 kilometer | 2.9 | 0.9 | 2.0 | 1.9 |
| Mount Weather, 2 kilometers | 4.5 | 1.8 | 2.7 | 2.9 |
| Drexel, Nebr., 1 kilometer | 3.7 | 1.5 | 2.2 | 2.4 |
| Drexel, Nebr., 2 kilometer | 3.4 | 0.8 | 2.6 | 2.5 |
| Ellendale, N. Dak., 1 kilometer | 4.5 | 1.0 | 3.5 | 2.1 |
| Ellendale, N. Dak., 2 kilometers | 5.5 | 2.0 | 3.5 | 2.7 |

We are not so much concerned with the comparison between tables as between values within the tables themselves, and not so much with the fact that particularly large or small values occur within the table, provided they occur irregularly. This can be judged best by looking at the tables directly, remembering that the individual tabulated values are the mean squares of the residuals and not the mean residuals themselves. Such an examination reveals the fact that the values are unsystematically distributed. For example, consider Table 4. Here we find the largest tabulated value is 18.46 for a west wind in September; the second largest value is for a north wind in January, closely followed by a southwest wind in August. The smallest value is for a northeast wind in April, the next larger is for an east wind in March, but a northwest wind in December gives a value almost as small. In Table 5, the largest values are to be found for a southwest wind in January and August, a fact which would seem to rule out seasonal factors. The smallest values occur for a northeast wind in January and a west wind in July, and for a northeast wind in October. Moreover, the range between the maximum and minimum values shown in Table 8 is small, being greatest for Ellendale and least for Drexel, which would appear to rule out geographical location as a factor of influence. Therefore, it appears that the errors are not systematic; and that they are indiscriminately scattered throughout the isopleths in such a manner that they may be considered as accidental. At any rate, if one were willing to admit the slightest effect of external influences in the distribution of the magnitudes of the residuals, it is plainly seen that such effects must be so small as to be hidden by the accidental variation.

*Frequency histograms.*—Having shown that the observations in a given isopleth are homogeneous, we can now proceed to discuss the data statistically. Frequency histograms have been drawn showing the number of observations having residuals of various magnitudes grouped in classes of whole degrees, as, for example, $-0.5°$ to $0.5°$, $0.5°$ to $1.5°$, $1.5°$ to $2.5°$, etc., and similarly in the negative direction. The histograms are presented herewith in figures 11 to 13, which show the residuals grouped symmetrically about the $y$-axis. This apparently indicates that the residuals obey the normal error distribution, and therefore the normal curve of error will best fit the data. These curves, computed for each of the six groups of data, are drawn from the equations appearing upon the diagrams.

*The normal curve of error.*—The equation for this type of curve, commonly known as the normal curve of error, is of the form:

$$y = \frac{h}{\sqrt{\pi}} e^{-h^2x^2}$$

or, in logarithmic form,

$$\log y = \log \frac{h}{\sqrt{\pi}} - h^2x^2 \log e$$

in which $y$ is the probability of the occurrence of a given value of $x$, $\pi$ and $e$ are the well-known constants, and $h$ is the *measure of precision* or index of the flatness of the frequency curve, and depends for its value upon the data under consideration. The value of $h$ is given by the relation:

$$h = \sqrt{\frac{n}{2\Sigma x^2}}$$

in which $n$ is the number of observations and $\Sigma x^2$ the sum of the squares of the residuals.

*The standard deviation.*—It is also of interest to know the value of the standard deviation, which is defined [16] as "those values of the departure which locate the points

[16] Marvin, Charles F.: Elementary notes on least squares, the theory of statistics and correlation, for meteorology and agriculture. MONTHLY WEATHER REVIEW, October, 1916, 44: 551–569.

on a frequency curve where the curvature changes from convex to concave—that is, points of inflection," or [17] "the square root of the arithmetic mean of the squares of all deviations, deviations being measured from the arithmetic mean of the observations," and, stated in the mathematical form, is

$$\sigma = \sqrt{\frac{\Sigma x^2}{n}}$$

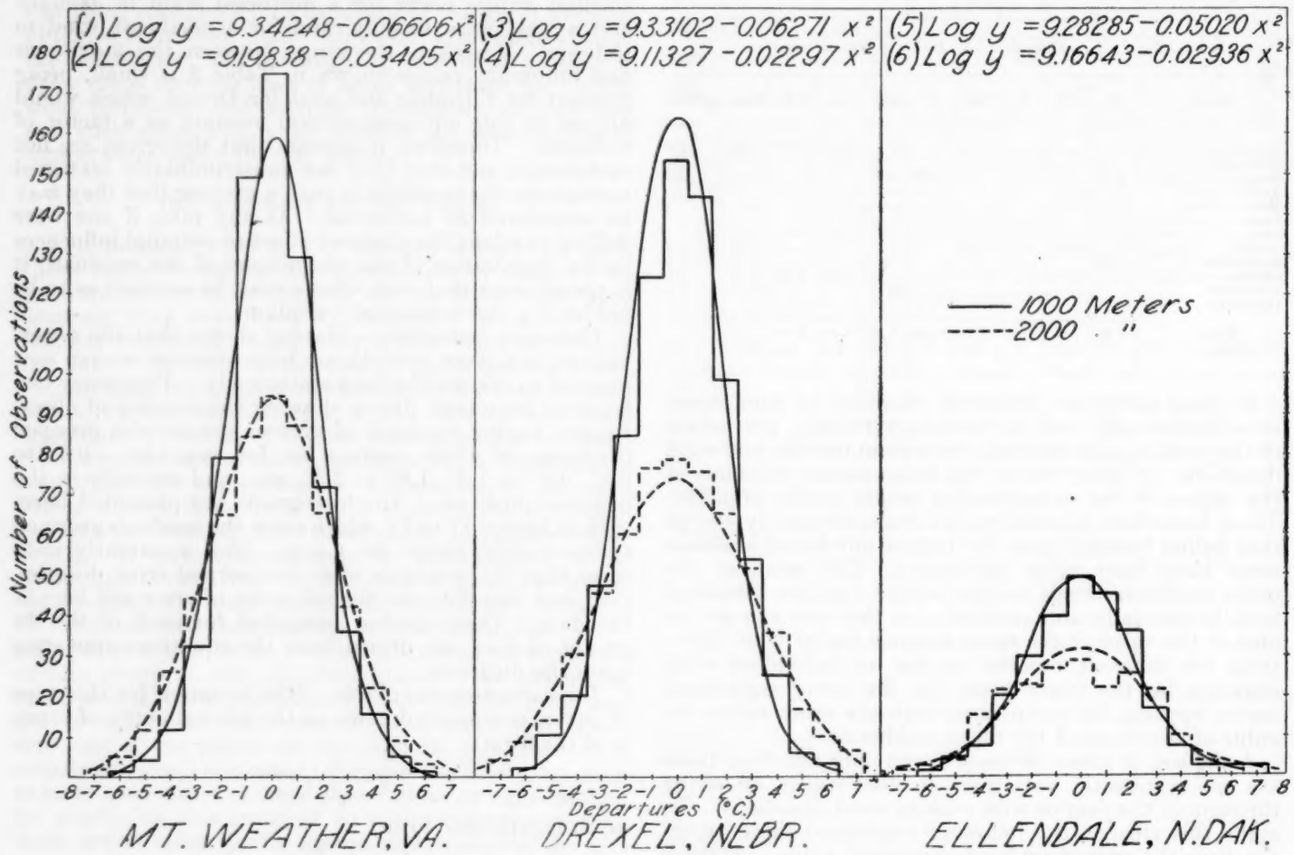
*The probable variation.*[18]—The probable variation of a given value from the mean is obtained from the relation

$$E = 0.6745\sigma$$

*Equations for the frequency curves.*—Having thus determined the values of the constant $h$, which, for the normal curve of error, is the only constant which must be determined, we can superimpose upon the histograms the curves represented by the equations derived from the data themselves. (See figs. 11, 12, and 13.)

THE HYPSOMETRIC FORMULA.

Laplace [19] has provided us with the well-known hypsometric formula, which has been so frequently and thoroughly discussed that nothing will be added by its presentation here in its complete and amplified form.[20]


(1) Log y = 9.34248 − 0.06606 x²
(2) Log y = 9.19838 − 0.03405 x²
(3) Log y = 9.33102 − 0.06271 x²
(4) Log y = 9.11327 − 0.02297 x²
(5) Log y = 9.28285 − 0.05020 x²
(6) Log y = 9.16643 − 0.02936 x²
Number of Observations
1000 Meters
2000 "
Departures (°C.)
MT. WEATHER, VA.
DREXEL, NEBR.
ELLENDALE, N.DAK.

FIGS. 11, 12, and 13.—Frequency curves of temperature departures (°C.), at Mount Weather, Drexel, and Ellendale, with their respective equations.

and this will be used later in showing how small are the errors obtained by this method in determining the mean temperature of the air column.

To this end the values of $n$, $\Sigma x^2$, $h$, $\sigma$, and $E$ have been tabulated.

TABLE 9.—*Statistical data for frequency curves.*

| | $n$ | $\Sigma x^2$ | $h$ | $\sigma$ | $E$ |
|---|---|---|---|---|---|
| | | | | °C. | |
| Mount Weather, Va., 1 kilometer | 720 | 2312.66 | 0.39 | 1.8 | 1.2 |
| Mount Weather, Va., 2 kilometers | 588 | 3705.77 | 0.28 | 2.5 | 1.6 |
| Drexel, Nebr., 1 kilometer | 785 | 3689.85 | 0.38 | 2.1 | 1.4 |
| Drexel, Nebr., 2 kilometers | 571 | 5443.81 | 0.23 | 3.1 | 2.0 |
| Ellendale, N. Dak., 1 kilometer | 255 | 1101.46 | 0.34 | 2.2 | 1.4 |
| Ellendale, N. Dak., 2 kilometers | 210 | 1593.25 | 0.26 | 2.7 | 1.8 |

A briefer statement of this equation is given by Prof. Kimball,[21] as follows:

$$\text{Log } B = \log B_0 - \frac{Z}{18400\,[1+0.00367\,(\theta+0.378\,\frac{e}{b}/0.00367)]}$$

in which $B$ is the reduced pressure in millibars at the upper level; $B_0$, the pressure as observed, in millibars; $Z$, the length of the air column, in meters; $\theta$, the mean temperature of the air column, in degrees centigrade; $\frac{e}{b}$ is the ratio of the vapor pressure to the pressure of dry air at 0° C., in metric units. It has been shown [22] that

[17] Yule, G. Udny: An introduction to the theory of statistics. London, 1916, p. 134.

[18] Prof. Marvin points out that while this expression is mathematically identical with "probable error," the latter refers to measurements *of a fixed quantity*, whereas the former more aptly refers to the changing values *of a variable quantity*.

[19] *Mécanique Céleste*, Liv. X, Chap. IV.

[20] For a statement of the amplified and complete formula of Laplace with its constants, see *Smithsonian Meteorological Tables, Fourth Revised Edition*, Washington, 1918, pp. xxxix–xli.

[21] Kimball, Herbert H.: On the relations of atmospheric pressure, temperature, and density to altitude. MONTHLY WEATHER REVIEW, 47: 156–158, 1919.

[22] Humphreys, Wm. J.: Physics of the air. *Journal of the Franklin Institute*, Sept., 1917, p. 386.

the error introduced into the reduced pressure by an error of 1 mm. in the value of $e$ in an air column whose length is as great as 3 kilometers is very slight indeed; hence it will be unnecessary in this connection to consider the term containing $e$. Thus, omitting this term, our equation becomes:

$$\text{Log } B = \log B_0 - \frac{Z}{18400\ (1+0.00367\ \theta)}$$

The purpose of introducing the hypsometric formula at this point is to determine what effect errors of various magnitudes in the value of $\theta$ will have under various conditions of surface pressure, with various lengths of air column, and with $\theta$ itself at various reasonable points on the scale. Therefore, with values of $Z$ varying by 500 meter intervals from the surface to 2,000 meters, with values of $B_0$ at 986.6 mb. (740 mm.), 1,013.3 mb. (760 mm.), and 1,039.9 mb. (780 mm.), and with values of $\theta$ at $-20°$ C., 0° C., and 20° C., the error in $B$ has been computed when $d\theta$, or the error in measuring $\theta$, varies by intervals of 1° C. up to 5°. This is shown graphically in figure 14. The abscissæ represent values of $Z$ in meters, and the ordinates are errors in $B$ in millibars. The various conditions of pressure and temperature are shown by the respective curves. It is seen at once that of the varying conditions surface barometric pressure has the least effect upon $B$, and that variations because of high or low values of $\theta$ are more marked. This information is presented in detail in Table 10.

TABLE 10.

| $B_0$ | | $\theta$ | $d\theta$ | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mb. | mm. | °C. | 1° C. | | | | 2° C. | | | | 3° C. | | | | 4° C. | | | | 5° C. | | | |
| Length of air column (m.) | | | 500 | 1,000 | 1,500 | 2,000 | 500 | 1,000 | 1,500 | 2,000 | 500 | 1,000 | 1,500 | 2,000 | 500 | 1,000 | 1,500 | 2,000 | 500 | 1,000 | 1,500 | 2,000 |
| | | | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. | mb. |
| 986.6 | 740 | −20 | 0.25 | 0.46 | 0.63 | 0.80 | 0.50 | 0.93 | 1.29 | 1.60 | 0.75 | 1.39 | 1.95 | 2.39 | 1.02 | 1.86 | 2.58 | 3.23 | 1.25 | 2.31 | 3.24 | 4.06 |
| | | 0 | 0.21 | 0.40 | 0.55 | 0.69 | 0.43 | 0.80 | 1.11 | 1.38 | 0.65 | 1.20 | 1.70 | 2.07 | 0.83 | 1.60 | 2.24 | 2.79 | 1.09 | 2.00 | 2.80 | 3.59 |
| | | +20 | 0.18 | 0.34 | 0.49 | 0.61 | 0.37 | 0.70 | 0.99 | 1.22 | 0.55 | 1.05 | 1.48 | 1.83 | 0.75 | 1.40 | 1.98 | 2.48 | 0.94 | 1.76 | 2.36 | 3.13 |
| 1,013.3 | 760 | −20 | 0.27 | 0.47 | 0.67 | 0.81 | 0.51 | 0.95 | 1.34 | 1.63 | 0.77 | 1.43 | 2.00 | 2.43 | 0.03 | 1.91 | 2.67 | 3.31 | 1.27 | 2.38 | 3.33 | 4.16 |
| | | 0 | 0.22 | 0.42 | 0.57 | 0.73 | 0.45 | 0.83 | 1.14 | 1.43 | 0.67 | 1.25 | 1.74 | 2.16 | 0.87 | 1.64 | 2.31 | 2.88 | 1.11 | 2.06 | 2.88 | 3.63 |
| | | +20 | 0.18 | 0.35 | 0.50 | 0.63 | 0.37 | 0.71 | 1.03 | 1.29 | 0.55 | 1.07 | 1.54 | 1.91 | 0.75 | 1.44 | 2.04 | 2.59 | 0.95 | 1.80 | 2.50 | 3.25 |
| 1,039.9 | 780 | −20 | 0.27 | 0.49 | 0.70 | 0.82 | 0.53 | 0.98 | 1.39 | 1.67 | 0.80 | 1.47 | 2.10 | 2.50 | 1.06 | 1.96 | 2.77 | 3.40 | 1.31 | 2.46 | 3.43 | 4.26 |
| | | 0 | 0.23 | 0.43 | 0.58 | 0.75 | 0.46 | 0.86 | 1.18 | 1.50 | 0.70 | 1.30 | 1.79 | 2.26 | 0.91 | 1.70 | 2.36 | 2.99 | 1.14 | 2.11 | 2.96 | 3.73 |
| | | +20 | 0.18 | 0.37 | 0.53 | 0.65 | 0.38 | 0.74 | 1.06 | 1.35 | 0.57 | 1.11 | 1.60 | 2.00 | 0.77 | 1.48 | 2.11 | 2.69 | 0.98 | 1.86 | 1.30 | 3.39 |

The reader may well point out that sea-level reductions in mountainous regions have been treated chiefly, showing that the long imaginary air columns and abnormal temperatures may combine to introduce large errors, and that this has been compared to long air columns in reducing to upper levels from data secured in eastern United States. What of the errors of reduction to sea-level in eastern United States, where the imaginary air column is short, averaging about 300 or 400 meters? Such comparisons are resolved into two divisions:

(1) *Short air columns:* Reduction to upper levels in the plateau region compared with reduction to sea-level in eastern United States.

(2) *Long air columns:* Reduction to sea-level in plateau region compared with reduction to upper levels in eastern United States.

Since the basic formula by which these pressures are reduced is the same in each case, the comparative value of the two methods (in so far as we may dare to compare them in this early state of upper air reductions) must lie in the relative merits of the temperature determination. It is not within the province of this paper to assume a critical attitude toward the present reductions; it is rather to assume such an attitude toward the method of upper air reductions and measure their accuracy, if comparisons may be resorted to, in terms of results by the present methods. As has been mentioned before, the plan of upper-air reductions has in its favor the fact that the temperature argument is a real, observable quantity, whereas the sea-level argument is merely an arbitrary value derived from surface conditions, and it is apparent upon the face of the proposition that there are many conditions in which local phenomena may lead to values of temperature which will give erroneous pressure values at sea level, even with relatively short air columns. Summing up the relative merits in this rather superficial manner (the only manner possible until it is within our ability to construct the maps of the upper air) it appears that (1) reduction through short air columns to sea level or to upper levels may be of approximately equal accuracy, since the error can not be very large in either case; (2) reduction through long air columns seems to be very satisfactory in the case of upper-air reduction, and, in many cases, to be very questionable in sea-level reductions; and (3) the importance of the location of the plateau region with respect to the paths of pressure areas across the country, and the fact that the plateau region is so extensive, render point (2) so important as to make worth while any attempt to improve such reduction.

In studying figure 14, it is found that in reducing to a level in the free-air an error of 5° C. in the mean temperature of the air column 2 kilometers in length will result in an error of about 4 mb. in the reduced pressure. In the case of Drexel, where the value of $h$ is lowest, i. e., where the frequency curve is the flattest, for the 2-kilometer air column, the chance that an error of this magnitude will occur is 1:4; but, at the same station for the 1-kilometer level the chance of a 5° C. error is 1:34. For the 2-kilometer level at Mount Weather the chance of a 5° C. error is 1:8, but for the 1-kilometer level it is 1:40. It is obvious that for the longer air column, the chance of large errors is much greater than for the shorter. But this is not discouraging, for a glance at the table to be given shortly, will show how generally small will be these errors, as based upon the probable variation.

Having determined the probable variations of the mean temperature of the air column from those from which the isopleths have been drawn, and also the amount of error subsequently introduced by air columns of various lengths, it will be of interest to see how these probable

variations will affect the reduced pressure at the upper levels. Basing our values upon figure 14 and Table 10,

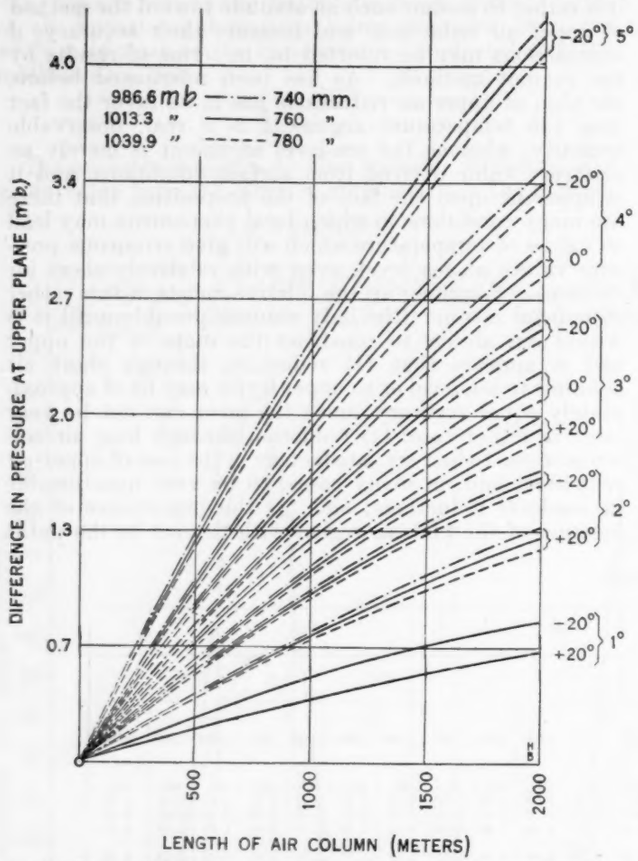



FIG. 14.—Pressure differences with various lengths of air column, corresponding to various errors in the mean temperature of the column with varying conditions of surface pressure and temperature.

let us obtain the pressure error due to the specific probable variations. A brief table will show this:

TABLE 11.—*Pressure errors due to errors in θ, under standard conditions.*

| Station. | E | Length of air column. | |
|---|---|---|---|
| | | 1,000 meters. | 2,000 meters. |
| | °C. | mb. | mb. |
| Mount Weather, Va. | 1.2 | 0.49 | ..... |
| | 1.6 | ..... | 1.15 |
| Drexel, Nebr. | 1.4 | 0.58 | ..... |
| | 2.0 | ..... | 1.43 |
| Ellendale, N. Dak. | 1.4 | 0.58 | ..... |
| | 1.8 | ..... | 1.29 |

These values appear to be very satisfactory. If we assume that the average elevation of the eastern half of the United States is 300 meters, the length of the air column in reducing to the upper level will average 1,700 meters, which will decrease the error shown above. In the mountain districts of the West, the error will decrease as the elevations become greater, and, if we can only obtain aerological information equivalent to that from the three eastern stations we have studied, it seems that upper-air reductions will be most reliable in the region where the sea-level reductions are the least reliable.

To show the practicability of this scheme, let us give an example of its use. Suppose the observer at Drexel (selected because we have data from that station) proposes to reduce his pressure to the level, 1 kilometer above sea level. At the time of observation, on the morning of September 1, he has a surface temperature of 10° C., and the wind direction is northwest. We find from figure 7 that, at that time, the correction to his surface temperature to obtain the mean temperature of the air column is −1.2° C., which, when applied, gives him the air column temperature of 8.8° C. Suppose that his corrected station barometric pressure is 970 mb., he will be able to tell from his tables that the pressure reduced through the air column 604 meters in length (Drexel's altitude is 396 meters) will be 901.6 mb. We know statistically that this observation will have a probable variation of less than 0.4 mb., which is certainly within satisfactory limits of accuracy.

## CONCLUSION.

As was stated in the beginning, this paper can not pretend to do more than penetrate the most superficial stratum of this great and important problem. As one progresses through the various steps of its most elementary aspects, new vistas are opening on every hand—vistas that are attractive and inviting, and withal necessary to explore before one can be positive in his survey of the field. Here have been dealt with only the temperature argument and its relation to pressure reductions, and that for only three stations. One can not speak with finality until the upper air over the entire broad reaches of the United States has been penetrated by kites or other means in a score or more of places, and until their meteorographs have brought to earth thousands of records of the conditions aloft. Of this, one is certain: That for the stations investigated the plan reveals itself in an orderly simplicity not suspected at the beginning. Why should it not for the stations yet to be studied? Is it too much to see in this study the nucleus of a method of pressure reductions and a step toward forecasting for aviation with greater accuracy and even toward solving the nettling problem of plateau barometry?

By way of summary, let us review the steps that have been followed to attain the results of this paper:

1. We assumed fundamentally that surface wind direction is a reliable criterion of temperatures aloft, at least within the lower 2 kilometers of the atmosphere.[23]

   Observations at Mount Weather, Va., Drexel, Nebr., and Ellendale, N. Dak., show that temperatures at the surface and aloft are subject to three principal controls—wind direction, geographical location, and seasonal variation. The last two affect temperatures at the surface and aloft in a nearly parallel manner, while wind direction produces a more marked effect upon temperatures aloft than at the surface.

2. There is an orderly and well-marked progression of differences between the mean temperature of the air column and surface temperature in different months and with different wind directions which can be utilized to obtain the mean temperature of the air column when the correction to be applied is known.

[23] While this assumption has been shown to be justified in America (see footnote 3) the work of Mr. W. H. Dines in Europe leads to the conclusion that such a relation is not to be relied upon. See The characteristics of the free atmosphere, *Geophysical Memoirs, No. 13*, Meteorological Office, London, 1919, pp. 47–76. Abstract by W. R. Gregg in MONTHLY WEATHER REVIEW, Sept., 1919, pp. 644–647.

3. The probable variation of the values is conveniently small.

4. The probable variation when converted into units of pressure, gives an accuracy of reduction which is very satisfactory, even for long air columns.

ACKNOWLEDGMENTS.

My thanks are due to Dr. Charles F. Brooks, who, through the several months I have been studying the problem, has been a willing advisor, a prolific source of ideas and suggestions, and a patient listener; also, to Mr. Willis Ray Gregg, who has shown an encouraging interest in the project, has given helpful suggestions, and who has supplied me with aerological data. I am grateful to Prof. Charles F. Marvin for conferences in which he not only assisted me on some of the statistical points but showed a stimulating interest in the problem; and to Dr. W. J. Humphreys, who has never been too busy to discuss the work as it progressed.

## TEMPERATURES VERSUS PRESSURES AS DETERMINANTS OF WINDS ALOFT.[1]

By W. R. GREGG, WEATHER BUREAU.

[Author's Abstract.]

From theoretical considerations a certain definite relation is expected to exist between the pressure gradient indicated on synoptic weather maps and the wind at a short distance, some four or five hundred meters, above the surface. Observations with kites and balloons show that this relation does exist, when averages are considered, but that wide variations are frequently found in individual cases. These variations are due partly to incorrect sea-level pressure reductions, partly to too much smoothing of the isobars, but principally to departures of horizontal temperature distribution from normal conditions. If, for example, there is a steep latitudinal temperature gradient, the free-air winds quickly depart from those indicated by the pressure gradient, and the principle of "gradient winds" breaks down. If, on the other hand, there is little temperature change over extended areas, the free-air winds conform very closely to the surface pressure distribution and indeed under these conditions anticyclones and cyclones are found to continue as such to great altitudes. The first type is most frequently found in winter and the second in summer, but occasionally in other seasons; in all cases it is the temperature distribution that is the controlling factor. Two illustrations are given: One shows the conditions on December 17, 1919, when a very steep south to north temperature gradient produced over the entire country, east of the Rocky Mountains, free-air west-northwesterly winds, quite at variance in many sections with the surface pressure distribution. (A note on this appeared in the MONTHLY WEATHER REVIEW, Dec. 1919, **47**: 853–854.) The other illustration shows the conditions on March 23, 1920, when absence of any marked latitudinal temperature gradient resulted in free-air winds closely following the surface isobars to heights of 4 to 8 kilometers.

Studies based upon observations in Europe indicate that anticyclones are warmer than cyclones at all levels in the troposphere. In the United States the reverse condition has been found. The reason for this difference is not that different processes are in operation, but that in Europe the effects of purely dynamic heating and cooling are more pronounced than are those due to the importation of cold and warm air by winds with a northerly or southerly component, whereas the reverse is true in the United States. The free-air pressure gradients resulting from changes in air density due to these currents of warm and cold air are decidedly different from those at sea-level and show that LOWS bend backward with altitude to the northwest and HIGHS to the southwest. Hence, in the upper levels winds with a northerly component (usually northwesterly) blow across the surface HIGHS, and winds with a southerly component (usually southwesterly) across the surface LOWS. These are average conditions. Variations from them are of course produced by variations in surface and free-air temperatures from the normal. A careful study of these temperature variations gives valuable aid not only in forecasting free-air winds, but also in predicting the movements of cyclones and anticyclones, and therefore the accompanying changes in surface conditions.

[1] Presented before American Meteorological Society, Washington, D. C., Apr. 22, 1920.

## DETECTION OF STORMS AND THEIR TRAVEL BY RADIO EQUIPMENT.

By Lieut. (j. g.) C. N. KEYSER.

[Navy Department, Washington, D. C., June 18, 1920.]

The perfection of radio apparatus for securing compass bearings by ships and aircraft paves the way for the development of a new phase of meteorological forecasting. The question of static has been the subject of considerable investigation by those interested in radio transmission as well as those interested primarily in meteorology and meteorological prognostication. Those interested in radio attacked the problem, first, in respect to its elimination from the field of radio transmission as a whole, and later, when this failed, in respect to the elimination of this interference from the radio receiver itself. The first problem resolved itself into finding out during what periods, in what particular localities, and under what conditions static disturbances prevented or hindered the receipt of radio messages, in order that times of transmission and locations for stations might be determined upon to eliminate this difficulty. These attempts at eliminating static did not prove successful. As a result the next attempt was made to eliminate static interference from the receiving set itself, and in this much greater progress has been made. The latest developments in radio receiving equipment have been successful in damping considerably, if not entirely eliminating, the interference from static disturbances.

The problem, from the meteorologist's standpoint, is not to devise means of eliminating static from radio receiving, but to associate the various types and intensities of static with the approach, movement, and intensity of local and general electrical storm, and of forecasting the approach of the same. The advent of aviation, more especially of "lighter-than-air" craft has made the forecasting of this type of storm of vital importance.

The matter of detecting storms in their travel by the use of radio equipment is still in its experimental stage and is as yet an open field for the experimenter as well as the amateur meteorological and radio enthusiast to enter. The time will probably come when storm detectors will be a part of the regular equipment of all meteorological stations, and when the reporting of static will be

an important part, during certain seasons, of all meteorological reporting services.

Some original and important experimental work along this line has been carried on by Lieut. W. F. Reed, U. S. N., aerological officer of the naval air station, Pensacola, Fla.[1] Lieut. Reed has been successful by the use of a radio receiver and direction finder to forecast the approach and movement of electrical disturbances over that particular portion of the Gulf covered by aviation operations from the Pensacola base. He has been able to detect the approach of these storms long before any local signs give warning of their approach and has been able to plot the movement of these storms, the directions from and to which they are moving, as well as their intensity. By this means he has been able to make the aviation operations from this base safer and much more successful. During the coming hurricane season it is to be hoped that this station, as well as others, may be able to carry on some extremely valuable experimental work, which in time may lead to the use of radio as a valuable aid to the hurricane-reporting service in the Gulf and Caribbean.

The field is large and there is need for considerable experimental work on the part of meteorologists acquainted and in touch with radio work. Our present forecasts of probability of the formation and approach of electrical disturbances and rather indefinite notice of their movements should in time be superseded by forecasts of a more definite nature, telling when to expect the disturbances at certain points, the direction and rate of movement, and their intensity. This type of service is at present rendered on a large scale in so far as the West Indian hurricanes are concerned, but in the case of nearly every one of these storms the position of their centers and the direction and rate of their movement is unknown for many hours, and in many cases days, by the forecasters who are charged with the task of reporting them, due to a lack of reporting stations over great areas of the Gulf and Caribbean during the progress of the storm. On the first notice of their formation and approach most vessels strike for port. Radio equipment, in addition to the broadened program of aerological observation, tide reports, and perhaps even vessel patrols now planned by the Weather Bureau, may in time fill this gap.

[1] Further details of Lieut. Reed's work will appear in a later issue of the REVIEW.

## AEROLOGICAL OBSERVATIONS IN THE WEST INDIES.

It is generally thought that tropical cyclones (hurricanes) move approximately in the direction and with the speed of the air in the strata at no great height above the surface. If this be true, it is very desirable to obtain observations of free-air wind conditions on all sides of hurricanes, particularly on the north and west sides. Although working under severe restrictions of funds and personnel, the Weather Bureau is undertaking a campaign of this sort for the hurricane season of 1920, July to November, inclusive. Stations are being equipped and will be operated at San Juan, P. R., and Key West, Fla., in addition to those in the Gulf States at which observations are now being made by the Weather Bureau at Groesbeck, Tex., and Leesburg, Ga.; by the Meteorological Section of the Signal Corps at Ellington Field and Kelly Field, Tex.; and by the Naval Aerological Section at Pensacola, Fla. Moreover, two new stations are being organized by the Navy at Colon and Santo Domingo. These nine stations form a network which, it is believed, will furnish information of great value in the study of these destructive storms and in forecasting their direction and rate of movement. Moreover, the observations will be taken regularly twice each day, irrespective of the occurrence of hurricanes, and will, therefore, give us data as to trades, antitrades, etc., of the utmost interest from a theoretical point of view and of inestimable benefit in their practical application. It is probable that some of the stations will be continued throughout the year and that many others will be added, if funds permit, during the next two or three years.—*W. R. Gregg.*

## THE MEASUREMENT OF TEMPERATURE, WITH SOME REMARKS ON OTHER PHYSICAL MEASUREMENTS, AND APPLICATIONS TO METEOROLOGY.[a]

By EDGAR W. WOOLARD.

### INTRODUCTION—UNITS IN GENERAL.

Lord Kelvin once wrote, "When you can measure what you are speaking about and express it in numbers, you know something about it, and when you can not measure it, when you can not express it in numbers, your knowledge is of a meager and unsatisfactory kind. It may be the beginning of knowledge, but you have scarcely in your thought advanced to the stage of a science."

The general Theory of Measurements is familiar to everyone: There are five *fundamentally* different entities which physics is at present considering, viz, those the *concepts* of which are symbolized by the words *space, time, matter, electricity,* and *entropy.*[1] Hence, as was pointed out by Rucker,[2] we need five *fundamental units* for the measurement of physical quantities; those usually chosen are the units of length, mass, time, permeability, and temperature, although better selections probably could be, and have been, made.[3] However, it has been found that by arbitrarily fixing the magnitudes of the units corresponding to the three indefinables of mechanics—space, time, and matter—we are then enabled, through the Theory of Dimensions, to derive units for all other quantities. In a few cases, such as when dealing with heat and electricity, additional units which are sometimes called *secondary* fundamental units appear, but probably it is only our ignorance of the true nature of the quantities involved which prevents us from expressing these, too, in terms of the three primary fundamental units.[4]

The practical application of the above theory consists of the selection of the fundamental units, the construction of standards, and the devising of measuring instruments which may be calibrated by comparison with the standards.

[a] Delivered in part before Am. Meti. Soc., Apr. 22, 1920.

[1] These five concepts, together with that of *number*, are necessary and sufficient for the complete description of the universe so far as it is at present known to us from observation: the objective universe, however, is itself composed of only matter and energy—the other indefinables are not "things," strictly speaking, but only creations of the mind, *conventional frames imposed on the universe* for convenience in study and interpretation. *Cf.* H. Poincare: Foundations of Science; and K. Pearson: Grammar of Science.

[2] A. W. Rucker: On the suppressed dimensions of physical quantities. Phil. Mag., (5), 27, 104-114, 1889.

[3] See, *e. g.*, R. C. Tolman: The measurable quantities of physics. *Phys. Rev.*, (2), 9, 237-253, 1917.

[4] W. Watson: Textbook of Physics, new ed. London, 1911, pp. 5, 334; Rucker, *op. cit.*

The selection of the fundamental units, the fixing of their sizes, and, indeed, the whole system of units, are perfectly arbitrary; hence it has come about that even to-day there are in well-established use several different systems, each possessing its own advantages and disadvantages. The intrinsic value and significance of a quantitative result, however, lies not in the symbolical expression of that result; for once a concept has been formed there is a tendency to regard the resulting quantities as identical with the symbols which represent them, abstract science being thus cut entirely adrift from the fundamental notions related to the experience in which it had its origin, and being reduced to a species of mechanical game played in accordance with a set of rules which when divorced from their origin have the appearance of being perfectly arbitrary; if this view is adhered to for purposes of convenience, it is necessary at the end of any process to reconnect the symbols employed with the ideas which originally suggested them, and thus interpret the results of the purely symbolical processes.[5] It is of the highest importance to state upon what particular basis a set of symbolical expressions rests, so that in the comparison of observations separated in space or time it may be determined what part of the differences are significant and what part are due merely to differences in the manner of expression. The problem of equivalents and conversions in the theory of measurements furnishes an excellent illustration of this principle, as we shall see.

It may be proper to mention, first, some questions of general metrology which are not, perhaps, always sufficiently emphasized. The yard and the meter, the two units of length which are in common use at present, are each *defined* as the *length of the respective standard.* Now the yard is an arbitrary length, the outgrowth of the rather confused and indefinite measures of early England; its length was definitely fixed by the construction of the original imperial standard yard by Bird in 1758; this original standard was destroyed in 1834 in the fire of the Houses of Parliament, and a new one was constructed and compared with the copies of the original which had been sent to various countries; while the differences in length which were found were unimportant, still there were differences; it must be remembered that because of the inherent limitations of man it is impossible to *exactly* duplicate a length, or *exactly* measure one; it is perfectly evident that there is only *one* accurate yardstick in existence, viz, the defining standard,[6] and all measurements must take account of not only the error of the instrument used, but also of the error of the standard and the error of the standardization. Such refined considerations, while perhaps not of much importance so far as individual observations are concerned, become of vital importance when observations are to be compared, for then all the measurements must be reduced to a common basis, and this can not be done until it is known to what basis each was reduced by the original observer. The meter is also an arbitrary length, although originally intended to be one ten-millionth of the earth's quadrant; it is not in any way superior to the yard except in the advantages conferred by the decimal character of the metric subdivisions. The meter is the length of the international meter, kept near Paris, which is a *copy* of the *original defining standard.*

The coexistence of more than one system of units necessitates the frequent use of the equivalent of a unit in one system in terms of the corresponding unit in another system; the yard and the meter, however, are incommensurable lengths to start with, and the always-present error of observation would prevent either one from being exactly measured in terms of the other, anyway, even though the defining standards themselves be used in the comparison; measurements performed at different times by different observers always give slightly different equivalents, some one of which must be arbitrarily adopted, usually by means of legislation on the subject.

In the United States of America, the unit of length is fixed by law to be the meter, which is defined to be the length of the international meter, a copy of which is kept by the Bureau of Standards; the yard is *defined* by law to be $\frac{3600}{3937}$ meter. In Great Britain, on the other hand, the unit of length is fixed by law to be the imperial yard, and the *meter* is defined by law to be 1.093614 yards. None of these equivalents is exactly that given by the best comparisons of the standards; the fact that the American and the British yard and meter are, therefore, probably slightly different from each other, and that the equivalents differ from each other and from the actual equivalents, shows the care needed when stating the results of measures of length. Somewhat similar remarks apply to measurements of other physical quantities.[7]

Clearly, in scientific work we should, whenever it is necessary to employ equivalents, use the true values as nearly as they can be determined, and not the arbitrary legal approximations. Whenever it is necessary to make use of tables of any kind, it must be carefully noted upon what basis they have been constructed. Meteorology furnishes a good illustration of the preceding principles.

So far as meteorology is concerned, the basis of numerical computations was set out authoritatively in the International Tables of 1890:[8]

> It has been the object of the meteorological authorities in all countries that the numerical values given in this publication should form the basis of all tables of conversion and computation which are employed by observers and students throughout the world, so that the meaning of any small differences in results should be freed from ambiguity on account of the process of computation.
>
> Meteorological questions nearly always depend for their solution on the comparison of results from different parts of the world, and comparability is often more important than extreme numerical precision, so that the values used in the computation of the International Tables are sufficiently accurate for all the computations of meteorogical practice and will remain so for many years to come, but in the meantime alterations in the accepted comparisons of fundamental standards of the various countries may receive, and some have received, the sanction of law, and it is hardly permissible to an official to display, or affect to use, tables which are ostensibly based on equivalents which are not lawful.
>
> The suggestion is sometimes lightly made that a new edition of the tables is required to bring them up to date, but the recomputation of tables is a work of great labor without any justification in the results to be achieved.
>
> Still, the progress in metrological exactitude which naturally follows the establishment of such institutions as the Bureau International des Poids et Mesures, the Reichsanstalt, the National Physical Laboratory, and the Bureau of Standards, must not be disregarded; and the horizon of meteorological computation has been much extended by the development of the study of the upper air which requires the tables for computation to be similarly extended over ranges which were outside the meteorological practice of 1890.[9]

The International Tables are based on the values of the equivalents which were then most widely accepted;

[5] *Cf.* E. W. Hobson: Theory of Functions of a Real Variable and the Theory of Fourier's Series. Cambridge Press, 1907, pp. 9, 10.

[6] It is not certainly known that the standards are not subject to secular change.

[7] See L. A. Fischer, History of the Standard Weights and Measures of the United States, U. S. Bur. Stand. *Sci. Paper 17*, 1905, especially pp. 379-381; also Centennial Celebration of the U. S. Coast and Geodetic Survey, Washington, 1916, pp. 25-39 (S. W. Stratton, The Bureau of Standards and its Relation to the U. S. Coast and Geodetic Survey).

[8] Tables Météorologiques Internationales publiées conformément à une decision du Congres tenu à Rome en 1879. Paris, 1890.

[9] British Meteorological Office, Computer's Handbook, Introduction, pp. 4-5, 1916.

the fourth edition of the Smithsonian Meteorological Tables [10] is based on the United States statutory equivalents, and on new values for standard gravity, density of mercury, etc., all of which must be considered when comparing older data and tables with modern ones.[11]

It is unnecessary to set forth here that which has been so often set forth, and which is almost self-evident, viz, the extreme desirability of *uniformity* in the matter of systems of units—*world-wide* uniformity, not only among scientists, but between scientists and laymen; only under such a condition—one which seems impossible to bring about—is it possible to have the fullest cooperation, appreciation, and understanding, and the most rapid advance in scientific knowledge.

Meteorology, being essentially the physics of the air, will employ the same system of units as physics employs, with such special adaptations and extensions as may be necessary. Until recently, however, there has been an estrangement between meteorology and the other physical sciences as regards the system to be employed; the same estrangement that still exists between scientific education and practical life. "If science is to be a part of practical life, the units of science and the units of practical life must be the same. One thing or the other: Either practical folk must learn to use metric units, or * * * men of science must use British units in their laboratory courses. The present divorce between education and practice is ruinous for both." [12] The intimate relations between meteorological work and the practical affairs of the general public for which the work is largely intended, has resulted in the use of the British units. At present "if in a country assembly for the advancement of science, an unknown stranger should get up and speak in metric units, the initiated physicist would at once say 'he must be one of *us*,' and the uninitiated meteorologist would say 'he is one of *them*.'" [13]

Furthermore, the difficulties of metrology are great enough without adding to them in any case by the adoption of a system of units which are not absolute, i. e., a system of units which depend for their values upon location in time or space; furthermore, if absolute units are the best for theory, as they undoubtedly are,[14] then they are the units of the future, for the practical applications of meteorology must ultimately be guided by theory just as those of astronomy are at the present day.[15] A vast number of considerations leave no doubt but that absolute units are also best for the use of instructors and lecturers who wish to interest students of physics and mathematics in meteorology, and for the presentation of the results of meteorological observations and studies to the public.[16] Various factors have contributed during the past several years to an increased use of the C. G. S. system in meteorology, even in the presentation of the daily reports to the public. Unfortunately this movement has come at a time when international agreement and standardization was impossible; we may look forward to such international action in the near future—some points have already been considered by the International Meteorological Conference.[17] Meanwhile some of the decisions of the international conferences on weights and measures in general are of special interest to meteorological circles.[18]

It has been said that meteorology stands in the way of the general adoption of metric units; this can no longer be maintained, however;[19] on May 1, 1914, the British Meteorological Office adopted metric units on its daily maps and reports and absolute units in its barometric work (recently F. temperatures were restored; absolute and metric units are now widely used in the official publications of the meteorological services in a number of countries, particularly in aerological work, although the transformation is still very far from being complete, especially in the United States.[20] Even in the present system of *metric* meteorological units, there is much that is unsatisfactory. "In referring to units of measurement it is customary to speak about the metric 'system' in contradistinction to the English want of system; but in meteorology the metric measures are not more systematic than the British, for both are arbitrary." [21]

In adopting the metric system meteorologists aspired to do what physicists had often aspired to do, but had never had the courage or coherence to carry out, viz, use pressure units for pressure measurements, reserve length units for length measurements, and change the thermometer scale so as to abolish negative temperatures, which are a survival of the time anterior to a knowledge of the conservation of energy, and have sooner or later to be explained away with much labor and practical inconvenience.[22] To what difficulties this has led, particularly as regards the absolute unit of pressure, is well known.[23]

Some of the difficulties, particularly in the case of meteorology, arise from the fact that the fundamental or "normal" system of units, such as the C. G. S., can not be equally convenient for practical use in all fields of science. The practical systems, derived from the C. G. S. system, have been formally defined by international action only in the case of electrotechnology;[24] the electrical engineers did something akin to what the meteorologists did when the latter made the unit of pressure $10^5$ C. G. S. units.

The question of thermometer scales, mentioned above incidentally, raises difficulties all its own; very hazy ideas of temperature and its measurement prevail in the minds

[10] Smithsonian Meteorological Tables, Fourth Revised edition, Washington, 1918.
[11] See the *Introductions* to the International Tables and to the Smithsonian Tables.
[12] Sir Napier Shaw: Units and Unity, *Nature*, 101, 326-328, 1918.
[13] W. N. Shaw: Pressure in absolute units. MONTHLY WEATHER REVIEW, **42**: 5-7, 1914.
[14] V. Bjerknes: The C. G. S. System and Meteorology. MONTHLY WEATHER REVIEW, **42**: 143-144, 1914.
[15] Sir Napier Shaw: The Outlook of Meteorological Science. MONTHLY WEATHER REVIEW, **48**: 34-35, 1920; Shaw: MONTHLY WEATHER REVIEW, **42**: 5, 1914.
[16] See Shaw, MONTHLY WEATHER REVIEW, **42**: 5-7, 1914; British Meteorological Office, Computer's Handbook, Introduction; and The Observer's Handbook, 1919 ed., pp. viii-xx; also, The Seaman's Handbook of Meteorology, 3d ed., 1918, pp. vii-xviii.
[17] MONTHLY WEATHER REVIEW, **47**: 852, 1919.
[18] E. g., as to the value of gravity to be employed in the reduction of the barometer, see *Nature*, 104, 13, 1919.
[19] Shaw: *Nature*, 101, 326-328, 1918.
[20] An excellent discussion of the difficulties of and the reasons for the adoption of the metric system in meteorology, the status of the system in the meteorological services of the several countries, and a complete systematic presentation of C. G. S. meteorological units are given in the British Metl. Office, Observer's Handbook, 1919 ed., pp. viii-xxvi; see also the Computer's Handbook, Introduction, pp. 5-14, 1916. The status of the metric system in general, in all countries, is set forth in the publications of the Bur. Int. des Poids et Mesures—see, e. g., Travaux et Memoires, t. xvi, Paris, 1917 (*Nature*, 104, 12-14, 1919; Science Abstracts, A, 22, 410, 1919), and Rev. Gen. d'El., 6, 311-312, 1919.
[21] On the adoption of the metric system in meteorology, consult: A. McAdie, New Units in Aerology, *Nature*, 93, 58, 1914; Shaw, *Nature*, 101, 326-328, 1918; New Daily Weather Map, MONTHLY WEATHER REVIEW, **42**: 35, 1914; Metric System for Aeronautics, MONTHLY WEATHER REVIEW, **44**: 627, 1916; A. McAdie, Suggested Reform in Meteorological Methods, MONTHLY WEATHER REVIEW, **36**: 372-374, 1908; R. Inwards, Metric System in Meteorology, *Quar. Jour. Roy. Metl. Soc.*, **33**: 165-171, 1907.
[22] Shaw: MONTHLY WEATHER REVIEW, **42**:5, 1914.
[23] Consult: C. F. Marvin, Nomenclature of the unit of absolute pressure, MONTHLY WEATHER REVIEW, **46**:73-75, 1918; G. Platania, Le Unita Assolute in Meteorologia, *Rivista Marittima*, Oct., 1918; Standard units in aerology, MONTHLY WEATHER REVIEW, **42**:141-143, 1914; F. J. W. Whipple, Absolute scales of pressure and temperature, *Proc. Phys. Soc. Lond.*, **31**:237-241, 1919, and *Chem. News*, 119, 189-191, 1919; Proposal to express all measurements of atmospheric pressure by a universal measurement of force, *Quar. Jour. Roy. Metl. Soc.*, **35**:132-134, 1909; Terminology in dynamic meteorology, *ibid.*, **40**:160-163, 1914; E. Gold, Barometer readings in absolute units and their correction and reduction, *ibid.*, 185-201, 1914; C. F. Marvin, Nomenclature of the unit of absolute pressure, *ibid.*, **44**:225-230, 1918; F. J. W. Whipple, Dynamical units for meteorology, *Nature*, **93**:427-428, 1914; R. A. Sampson, Meteorological unit of pressure, *Nature*, 101, 353, 1918; A. McAdie, Standard units in aerology, *Science* (N. S.), **39**:391-392, 1914; A. McAdie, Unit of pressure, *ibid.*, **45**:385, 1917; Guillaume, Progres du Systeme metrique, 1913, pp. 43, 79; Phys. Soc. of France, Recueil de constants physiques, 1913, p. 6; Brit. Assoc. Adv. Sci., *Rept.* 1873, pp. 222-225; *Jour. Amer. Chem. Soc.*, **26**:408, 1904; **36**:491, 1913; *Phys. Rev.*, **5**:212-229, 1915; Smith. Phys. Tables, 1916, p. 346; MONTHLY WEATHER REVIEW, **44**:191, note 4, 1916. In conformity with the system of naming units after great scientists, the names "pascal" and "abbe" have been proposed instead of "bar." The U. S. Army shows a strong inclination to completely abandon even the partial use of the meteorological and other metric measures which it initiated during the recent war.
[24] See U. S. Bur. Stand. *Sci. Paper 292* and *Circular 60*, on the International electrical and magnetic units; and Proces-Verbaux, Comite Int. des Poids et Mes., 1911, p. 209, Comptes Rendus, Conference Generale des Poids et Mes., 1913, pp. 14, 51-60.

of most people, including many professional physicists; confusion and inaccuracies are present in many textbooks. Therefore it seems quite appropriate to give the whole subject of thermometry a special and complete exposition—one which is applicable to precise physical laboratory measurements as well as to meteorological observations.

## THERMOMETRY.

The molecular and kinetic theories of matter, although 25 centuries old, have only recently, through the demonstration of their soundness,[25] been raised above the position of mere convenient working hypotheses. Until the establishment of these theories thermometry, although nearly as ancient as they, was only a rough empirical subject with no theoretical foundations; hence, present-day precision thermometry, at least on the theoretical side, is essentially a modern development. In an exposition of the principles of thermal measurements, it may therefore be assumed as an already established fact that heat is a form of *energy*, and one which stands in a very special relation to matter—viz, it is that part of the total internal energy of matter which is due to the motions of the molecules relative to one another. The determination of the absolute amount of heat contained in a given mass is the measurement of the sum total of the kinetic energy of the molecules with reference to each other; if the molecules could be brought to rest among themselves the mass would then possess no heat. Since heat is a form of energy, a quantity of it may be dynamically measured by determining the number of units of work to which the heat is equivalent.

To prevent possible confusion in the mind of the reader, it may be stated here that radiant energy is not heat, although it is converted into heat upon being absorbed by any object in its path; and, conversely, heat has a great deal to do with the production of radiation. The transference of energy by radiation and absorption constitutes the most important agency in the diffusion of heat.

The term "heat" is employed in ordinary language with a number of slightly different meanings. The sense of touch first gives rise to the concept of heat, and from this there arises the further popular conceptions based on the different sensations produced by bodies when termed hot, warm, or cold, which imply a crude conception of a continuous scale, the place of any body in this scale being denoted by its *temperature*, so-called; the hotter body is said to have the higher temperature.

From the nature of heat, it is self-evident that a large and a small body, each composed of the same substance, may possess equal *degrees* of molecular motion, and hence give rise to identical physiological sensations, and yet contain vastly different total *amounts* of molecular motion, i. e., of heat, according to their respective masses or total numbers of molecules. Thus the temperature of a body is, qualitatively speaking, its degree of hotness, in contradistinction to the actual quantity of heat present in the whole body.

In scientific work it is, of course, necessary to have a more definite and reliable indication than is afforded by the sense of touch; measurements of heat have necessarily been based on some *measurable physical effect* of heat, rather than on any difference of physiological sensations, the scale of measurement being so chosen as to give hotter bodies higher temperatures in agreement with our ordinary ideas of differences of hotness or coldness so far as the two can be compared.

The phenomenon which has been most generally employed for the above purpose is that of the volumetric expansion of bodies with increase of heat content. This effect of heat was known in very ancient times. *The expansion, while not varying exactly in a simple proportion to successive increments of heat, still approaches closely to a linear relation.* Expansions or contractions, then, of a body, relative to any initial volume arbitrarily selected as a starting point, measure *relative* increments or decrements of heat, *equal changes in heat content corresponding to nearly equal changes in volume.*

In the writings of Philo of Byzantium (third century B. C.) and of Hero of Alexander (first(?) century B. C.) we find the earliest application of these principles of which we know—viz, descriptions of an apparatus which represents the primitive idea of a thermoscope.[26] A translation of Hero's book was studied by Galileo, Porta, and Drebbel, and gave, about the year 1600, to all three men the idea of constructing a thermoscope. Galileo revived the instrument in the form of a glass globe opening into a narrow tube, and partly filled with water, the whole being inverted and dipped into a vessel of water; the height at which the water stood in the tube as the air in the globe expanded and contracted indicated the relative thermal condition of this air; since the relatively small amount of matter composing the instrument permits it to come quickly into thermal equilibrium with the surroundings, it is easy to see how the indications of a thermoscope are also qualitative indications of the thermal condition of the immediate environment; for quantitative relationships to be established, the conditions at equilibrium must be supplied by theory.

Galileo's thermometer was extensively introduced by Sanctorius of Padua; within a few years the instrument had been inverted, and otherwise improved by Galileo and his pupils, and by 1641 the modern type of thermometer was in use—a bulb filled with spirit of wine or other liquid, the tube being sealed, and graduated in accord with some standard system. In such an instrument, increment of heat (i. e., of amount of molecular motion) in the surrounding medium will, at equilibrium, cause the *same* increments of heat in the material of the thermometer bulb, *relative to the initial amount* (regardless of whatever quantitative relations may exist); the resulting proportional expansion of the thermometer fluid may therefore be used to measure the *relative* heat content of the environment, without any knowledge as to masses, specific heats, or coefficients of expansion[27]—provided always that the *thermometer fluid* has a constant coefficient of expansion which bears a linear relation to heat increments: This latter condition is not met with in the case of any actual substance, as we have noted, and consequently corrections must be determined and applied to eliminate the error thereby introduced.

We thus *define differences of temperature as proportional to differences of heat content*, the latter being measured by the expansion of the material in the thermometer bulb indicated by an arbitrarily graduated scale on the stem.

The unit of *absolute* quantity of heat is then *defined* as the amount of heat necessary to cause a certain specified increment in the heat content, i. e., a certain specified temperature change, of a certain mass of a certain substance, thus making the whole art of calorimetry depend upon that of thermometry:

[25] *Cf.* R. A. Millikan: The Electron, pp. 6–10, 1917.

[26] G. Hellmann: The dawn of meteorology. *Quar. Jour. Roy. Met. Soc.*, 34, 226–228, 1908.

[27] The loss of temperature by a hot body is, after equilibrium, not generally equal to the gain of temperature of a cold body in contact with it, but that of degree of molecular motion obviously is. Account must be taken, in practice, of the expansion of the bulb itself, too.

*The temperature of a body is its thermal state considered with reference to its power of communicating heat to other bodies;* the *continuous series of such thermal states* passed through by any one substance, as its heat content is continuously increased or decreased, *defines a temperature scale;* any arbitrary system of *uniquely designating* or labeling each temperature of the scale constitutes a *thermometer scale*—when some particular property of some particular substance, for example the volumetric expansion of mercury, or the resistance of a platinum wire, is selected to define a scale of temperatures it still remains necessary to select some arbitrary system, say of numbers, by which to label uniquely each successive thermal state which is indicated to us by means of the use of that property.

A thermometer constructed according to the above definitions will, then, indicate uniquely the temperatures and temperature changes of its environment, and hence, from the definition of temperature differences, also indicate differences of actual heat content, so that, arbitrarily defining the unit of absolute amount of heat as we have done above, it is clear that with the mechanical equivalent of this latter unit known our problem is completely solved. The total amount of heat in a body can then be calculated provided we know the mass, temperature, and the specific heat at all temperatures; and in any case *changes* in the heat energy can easily be experimentally determined, although we can not, in this paper, go into the details of calorimetry.

Obviously, working temperature scales and thermometer scales should be so chosen that results expressed in terms of them may be capable of ready translation into terms of molecular processes and conditions as indicated in the preceding paragraph, for temperature measurements are only a means to an end. Our sensations provide us with a simple and general criterion for deciding whether the temperatures of two different bodies are equal or unequal, and by a further convention we tell with certainty what is the sign of the difference in temperature between two bodies; diffusion of heat always takes place from hotter to cooler bodies. Now, our preceding discussion, as well as the mere fact that we speak of the body which cools off the more quickly as having the *higher* temperature far more often than we speak of it as having the *greater* temperature, betray the fact that we do not look upon temperature as a quantity measurable in the usual sense. When we go beyond the bare statement that the temperature of one body is equal to, lower (less) than, or higher (greater) than that of a second body and *assign numerical values* to temperatures by means of arbitrary graduations on the stem of a thermometer, we are, strictly speaking, not *measuring* temperatures, but *numbering* them; there *is* no such thing as *measuring* temperature in the sense in which the term "measure" is commonly used in physics, i. e., there is no such thing as direct comparison of two intervals of temperature which are not coincident at both ends. Temperature is not an extensive magnitude, i. e., it does not possess an additive nature such that a given quantity of it may be regarded as being the sum of a number of smaller quantities of the same kind; the "measurement" of such a quantity as temperature must be effected by some device in which the magnitude to be measured is put into a one-to-one relation with a series of quantities which *have* extensive magnitude. In other words, we adopt some method by which we may assign to each separate temperature a definite number, and there must be a one-to-one correspondence. The method must be unequivocal in assigning one, and only one, number to each temperature and in never giving the same number to two different temperatures. This is the one essential fundamental principle in constructing a scale of temperature. If we conform to it, we are free in other respects to choose our scale as we please, the choice being, in any case, arbitrary.[28]

For a century after Galileo's time great confusion prevailed; many different substances were used in the thermometer bulbs, and innumerable different systems of arbitrary graduation for the stems were employed. Out of the chaos there finally emerged three systems, because the founders of these systems manufactured instruments of such high quality and in such great numbers that they came to be recognized as standard.[29] The Fahrenheit thermometer originated at Danzig in 1714; mercury was used for the fluid, and the two known temperatures—the freezing and boiling points of water—which had previously been employed by Huyghens in 1665 were utilized to give the graduation. The centigrade scale was introduced by Celsius and Linnæus at the University of Upsala in Sweden, 1742, and the Reamur by the French physicist of that name, 1731, although both were later somewhat modified by others.

The main object to be secured in thermometry is that all thermometers shall be strictly comparable; the simplest means of obtaining this object is by comparing all thermometers, directly or indirectly, with some standard instrument; when thus properly corrected, all thermometers will be copies of the same original and will agree in their indications. Thermometers may then be constructed of other fluids than the one used in the standard, or by measuring some effect of heat other than that made use of in the standard; the condition implied in all cases being that the thermometers shall all be graduated so as to agree with the standard, and also that the particular property of matter made use of shall always give the same indication when the temperature is brought again and again to the same value.

Now, in spite of the fact that, as we have specifically stated, temperature differences are proportional to differences of heat content, it is far more convenient in practice to *define equal increments of temperature as those which give equal increments of, say, volume to the substance employed;* this, of course, does not agree with the previous definition, because all substances differ from each other in their physical properties, and all depart somewhat from an ideal behavior, so that although no matter what fluid be employed in a thermometer bulb it will, in accord with this second definition, indicate temperature increments quite satisfactorily, yet two thermometers employing different fluids will not ordinarily read exactly the same numerically (supposing the same system of graduation to be used for both) when exposed to identical thermal environments; and equal *intervals* on either one will correspond to irregularly variable increments of *heat. Each thermometer defines its own scale of temperatures;* and either we must arbitrarily adopt a standard by merely *conventionally agreeing* upon some one instrument and then working out the complicated series of corrections necessary for the translation of its indications into terms of molecular processes, or we must discover a temperature scale independent of these vagaries of matter for our standard. The selection of a standard temperature scale is, of course, independent of the selection of a thermometer scale, or system of labeling, to go with it. The position in the *temperature* scale of one or more easily

[28] Edgar Buckingham: Note on the Radiation Formulas and on the Principles of Thermometry, MONTHLY WEATHER REVIEW, 31: 179, 1903; J. Rice, *Scientific American Supplement*, May 3, 1919, p. 287.

[29] See Cajori, History of Physics, for a history of thermometers.

reproducible *standard temperatures* must be known, and the whole scale should conform to nature and be easily and accurately reproducible at any time; then the arbitrary thermometer scale may be agreed upon by selecting some point in the thermometer scale as a *zero point*, some continuous portion as a *fundamental interval*, and some fraction of the fundamental interval as a *unit*.

The mercury-in-glass thermometer was originally taken as the standard. It was stated, among other things, that mercury "expands uniformly," and yet no standard of reference was given by which this uniformity was supposed to have been established. In time, it was found that slightly different temperatures would be indicated by different instruments, depending upon the kind of glass employed; differences were found even in thermometers made from the same ingot of glass; in addition, mercury, as pointed out before, gives us an arbitrary scale of temperature differing, probably, from every other similar scale; air does not expand quite uniformly if mercury be the arbitrary standard, and vice versa. After the discovery of the gas laws, some monumental researches on the expansion of gases were carried out by Regnault, who, after studying the whole subject of thermometry very critically, introduced the use of the air thermometer as a standard, comparing its indications with those of a mercurial instrument; later investigators experimented with other gases similarly; but because of the differing properties of the various gases, none of which is perfect, the gas scales also are incapable of giving a solution of our problem.[30]

However, Lord Kelvin finally showed from theoretical considerations that Carnot's function supplies a means of measuring temperatures independently of the properties of any particular substance. *Carnot's Theorem* asserts that the efficiency of any perfect thermal engine working periodically and reversibly by taking in heat from a hot body and giving out heat to a cold body, is the same for all such engines and for all substances employed in them, being a function of only the temperatures of the hot and cold bodies. If $E$ be the efficiency, and $Q_1$ and $Q_2$ the heat taken in and given out respectively, then [31]

$$E=\frac{Q_1-Q_2}{Q_1},$$

which may be put in the form

$$\frac{1}{1-E}=\frac{Q_1}{Q_2}.$$

Since, from the theorem,

$$E=f(t_1, t_2),$$

we have

$$\frac{Q_1}{Q_2}=f(t_1, t_2).$$

If we assign to any two temperatures *numbers* such that

$$\frac{\theta_1}{\theta_2}=\frac{Q_1}{Q_2},$$

we have the thermodynamic scale introduced by Lord Kelvin in 1854. Then,

$$E=\frac{\theta_1-\theta_2}{\theta_1}.$$

It is easily shown that the scale of temperatures which would be defined by a perfect gas, employed with a thermometer scale with its graduations numbering from the point at which the gas contained no heat—no molecular motion—whatever, would satisfy the above condition.[32] A perfect gas is one which would obey Boyle's Law perfectly throughout all ranges of temperature.[33]

Since the coefficient of expansion of a gas is closely 1/273 on the centigrade scale, the extrapolated point on the scale of the constant-volume hydrogen thermometer at which the gas pressure would vanish—corresponding under the ideas of the kinetic theory to a complete absence of heat—is about −273° C., the so-called "absolute zero." The zero of the thermodynamic scale is identical with the absolute zero of a perfect gas, and since the absolute thermodynamic temperatures and absolute temperatures on the gas scales are both of frequent occurrence, it is desirable to employ a thermometer scale such that the numerical symbol of a temperature will be the same on both scales. The *thermodynamic scale of temperatures is the only one which is independent of the properties of some one particular substance*, and evidently is not realizable in practice; at the same time, from its relation to the gas laws, it is clear that on this scale, temperature differences *are* proportional to heat increments; in this case, *our two different definitions of temperature differences are equivalent.* Our considerations have brought us to two independent and discordant temperature scales, (1) the theoretical thermodynamic scale which can not be realized in any practical working thermometer, and (2) a practical instrument depending upon the volumetric expansion or other physical properties of substances we may find it convenient to employ, but the indications of which are somewhat difficult to translate into terms of molecular processes. If we can accurately determine the *deviations at all temperatures* of any one or all of these practical thermometers from the thermodynamic scale, then our problem will have been completely and accurately solved in spite of the difficulties introduced by the irregularities in the behavior of matter.

As a matter of fact, the scale defined by any one of the more permanent real gases is a very close approximation to the thermodynamic scale; furthermore, by conducting appropriate investigations upon the flow of actual gases through porus plugs, their deviations from the behavior of perfect gases can be ascertained.[33] Experiments show that in the case of hydrogen the deviations from the thermodynamic scale are so small except at very low and very high temperatures that a hydrogen gas thermometer may be taken for all practical purposes as a realization of the ideal scale.

The equation $\theta_1/\theta_2=Q_1/Q_2$ defines only the ratio of two temperatures and not their numerical values; when the further condition is imposed [34] that the temperatures of the melting point of ice and condensing point of steam shall differ by any arbitrary number of degrees, then the location of these points fixes the numerical value of every other temperature independently of the laws of expansion of any particular substance.

On October 15, 1887, the International Committee on Weights and Measures passed a resolution adopting as the standard thermometric scale for the international service of weights and measures the *centigrade scale of the hydrogen thermometer*, having the zero point of the *thermometer* scale at the *temperature* of melting ice; the

[30] The initial pressure is a factor in the use of gas thermometers; the barometric pressure of course influenced the thermoscope of Galileo. The details of the construction and manipulation of the various instruments of thermometry must be sought elsewhere than in the present paper.

[31] For the complete explanation of the following derivations, see Preston, Theory of Heat, 2d ed., 1904, pp. 709–713.

[32] Preston, op. cit., p. 716; Edgar Buckingham, On the definition of the ideal gas, U. S. Bur. Stand. *Bull.*, *6*, 413, 1909.

[33] *Cf.* Buckingham, op. cit.

[34] Preston, op. cit., p.714–716.

*fundamental interval* the difference of temperature of melting ice and of the vapor of boiling distilled water, all under standard atmospheric pressure; the unit or *degree* $\frac{1}{100}$ of the fundamental interval; the hydrogen in the thermometer to be taken at an initial pressure of 1 meter of mercury—that is, $\frac{1000}{760}$ or 1.3158 times the standard atmospheric pressure. Now, if we thus specify that the numerical values of the temperatures of the freezing and boiling points shall differ by 100, and that the temperature of the freezing point shall be denoted by 0, than the *centigrade thermodynamic* temperature is the number of degrees from the ice point to the given temperature to be numbered; by "the correction of the gas scale to the thermodynamic scale" is meant the difference between the centigrade scale of the gas thermometer and the centigrade thermodynamic scale, the latter being now the standard scale; these corrections therefore vanish at 0 and 100.[35]

Owing to the great experimental difficulties involved in the use of precise gas thermometers of any form and the limitations in range of temperature they can cover, it is necessary to establish a practical working scale which should represent the thermodynamic scale as closely as possible in the light of existing knowledge and be definite and easily reproducible. Such a working scale may be defined by means of certain fiducial temperatures or fixed points, together with a specification of the method of interpolating between the fixed points. Then the practical working instruments which meet the needs of ordinary observational work and, in some cases, by safe extrapolations, extend the range to temperatures otherwise unattainable with the gas thermometer itself, may easily be standardized by comparison with this working scale.

The leading laboratories of the world have adopted the *platinum resistance thermometer* as the working or interpolation instrument in the interval −190° to 450°, the fixed points or fiducial temperatures being those defined by the following phenomena, where the values are those on the centigrade thermodynamic scale:[36]

| | |
|---|---|
| Boiling point of oxygen | −183.0 |
| Sublimation point of carbon dioxide | − 78.5 |
| Freezing point of water | 0.0 |
| Boiling point of water | 100.0 |
| Boiling point of sulphur | 444.6 |

*Thermoelectric junctions*, composed of suitable combinations of metals, also serve for effecting temperature measurements, and in the interval 450° to 1,100° the platinum thermocouple—90 per cent platinum, 10 per cent rhodium—is used as the interpolation instrument, being calibrated at the freezing points of zinc (419.4°), antimony (630.0°), and copper (1,083.0°).

Finally, *optical pyrometers* must be resorted to in the measurement of extremely high temperatures. The ingenuity, art, and skill of the physicist are taxed to the utmost to adequately evaluate or number all the temperatures which come within his experience on the one ideal thermodynamic scale which justly constitutes the accepted standard.

The *mercury-in-glass thermometer*, carefully standardized by direct or indirect comparison with a standard gas thermometer, is a familiar example of an exceedingly convenient and widely used instrument for temperature measurements over a certain range.[37]

It will now be recalled, however, that the most desirable scale is not the centigrade thermodynamic, but the thermodynamic employed with a system of graduation starting at the absolute zero; it is evident that to reduce the reading of a standardized thermometer to this *absolute thermodynamic scale* we merely add to the reading, after the latter is corrected to the thermodynamic scale, the *thermodynamic temperature of the ice point*. After having specified that the fundamental interval shall be 100°, there are several methods of evaluating the ice point on the thermodynamic scale, but the problem is far from being simple, and there is still some uncertainty in the value; it is probably very close to 273.°13.[38] For practical purposes we may add 273 to the centigrade reading and call the resulting thermometer scale the "Approximate absolute."[39]

In English-speaking countries neither the absolute nor the centigrade thermometer scales are in common use outside the laboratory. As Sir Napier Shaw says, "Our practice of using one set of units in the laboratory and another set in practical life can only be described as stupid." The absolute thermodynamic scale has some reality about it—it conforms to physical phenomena and to the nature of things as we find them, instead of being based upon the predilections of men.[40]

In conclusion, I wish to acknowledge the helpful suggestions and interest of Prof. C. F. Marvin, Chief of Bureau, during the preparation of this paper.

[35] Edgar Buckingham: On the establishment of the thermodynamic scale of temperature by means of the constant-pressure thermometer, U. S. Bur. Stand. *Sci. Paper 57*, 1907, pp 237-243, 274. The corrections are tabulated in Guillaume, Les Recents Progres du Systeme Metrique, p 48, in Travaux et Memoires du Bureau International des Poids et Mesures, t. XVI, 1917.

[36] Waidner, C. W., et al: The standard scale of temperature, *Jour. Wash. Acad. Sci.*, **10**, 276-277, 1920; U. S. Bur. Stand., *Circ. 35*, Melting points of the chemical elements and other standard temperatures, 1919.

[37] The numerous publications of the U. S. Bureau of Standards may be consulted for the details of the theory, construction, and manipulation of the various classes of instruments mentioned above. On standardization, etc., see, e. g., U. S. Bur. Stand. *Circ.* 8, Testing of Thermometers, 1911; *Sci. Paper* **60**, On the standard scale of temperature in the interval 0° to 100° C., by C. W. Waidner and H. C. Dickinson, 1907.

[38] Buckingham, op. cit.; Preston, op. cit., pp. 714-717.

[39] C. F. Marvin: Shall we revise our nomenclature for thermometric scales? MONTHLY WEATHER REVIEW, **43**; 534, 1917; *Nature, 101*, 14, 1918; Smithsonian Meteorological Tables, 4 ed., xi-xvi, 1918.

[40] Maxwell: Theory of heat, chap. 2; Shaw: Units and unity, *Nature*, **101**, 325-328, 1918; A. McAdie: Thermometer scales, *Science* (N. S.), **43**, 854, 1916; MONTHLY WEATHER REVIEW, **37**, 92, 1909; *Geographical Review*, **4**, 214-216, 1917.

[To face p. 271.]

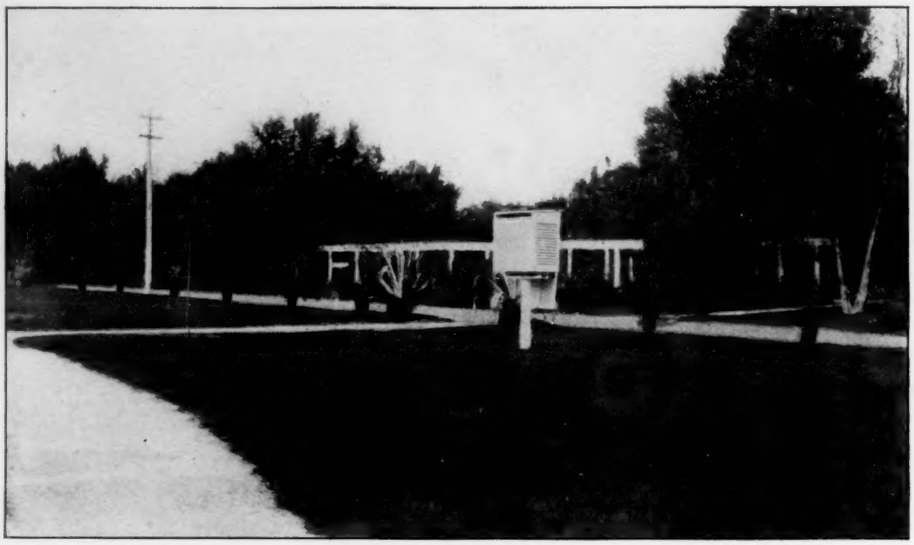


FIG. 1.—Location of "sun" shelter in Gage Park. Camera pointing toward the northwest.

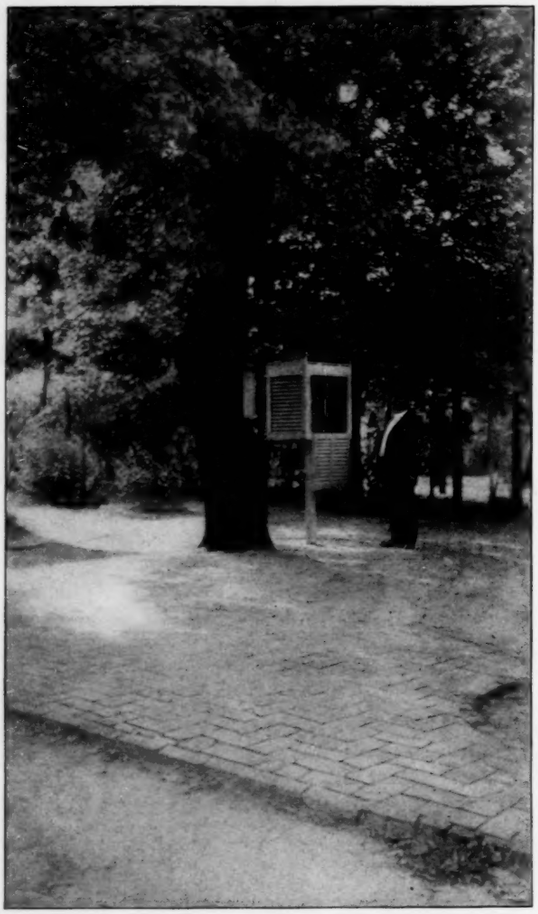


FIG. 2.—First location of "shade" shelter at Gage Park, 141 feet north of "sun" shelter. Camera pointing toward southwest.

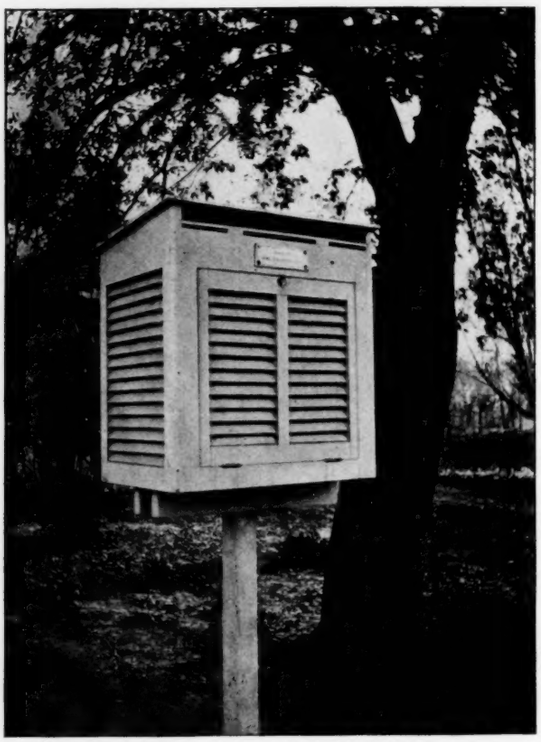


FIG. 3.—Second location of "shade" shelter at Gage Park, 150 feet west of "sun" shelter. Camera pointing toward southwest.

## SHADING INSTRUMENT SHELTERS.

By S. D. FLORA, Meteorologist.

[Weather Bureau Office, Topeka, Kans., May 25, 1920.]

The present style of instrument shelter was adopted by the Weather Bureau early in the nineties after a long and careful investigation of the best exposure for thermometers and is generally conceded to be the most practicable shelter in use in obtaining the temperature of the free air. It was assumed that the use of the double top and white paint, combined with the excellent ventilation afforded by the louvered sides, would eliminate from the thermometer readings within, the direct heating effect of the sun's rays on the shelter as well as the loss of heat by radiation from the shelter itself, so that for all practicable purposes it would give the temperature of the free air as accurately if fully exposed to the sun's rays as it would in a shady location, provided in each case it had a free circulation of air about it and there was no interference due to reflected heat from nearby objects.

The question of whether the standard instrument shelter was really efficient in overcoming the effects of insolation and radiation was brought to the attention of Mr. P. C. Day, Chief of the Climatological Division, United States Weather Bureau, during his visit at Topeka in the fall of 1916, and at his suggestion arrangements were made for a series of readings from thermometers in a shelter freely exposed to sunlight and also from thermometers in a nearby shelter that was shaded.

Two instrument shelters of the type in general use at the cooperative stations of the Weather Bureau and two sets of standard maximum and minimum thermometers were located in the summer of 1917 a mile west of the limits of the city of Topeka, in Gage Park, on ground that was gently rolling. One shelter was placed over thick sod, entirely in the open (see fig. 1), and the other 141 feet north under a spreading box elder tree at the rear of the residence of the park superintendent, where it was densely shaded all day during the season that the tree was in leaf—approximately from April 15 to October 15—and thinly shaded by the naked limbs of the tree the remainder of the year, but had an excellent circulation of air about it. (See fig. 2.) The ground between the shelters and for a considerable distance in every direction is almost level.

Mr. E. F. A. Reinisch, park superintendent, kindly consented to record the readings of the two sets of thermometers and reset them each evening, and it is to his faithful and painstaking work that credit should be given for the successful completion of the series of comparative readings.

At the end of 1918 the "shade" shelter was moved to beneath another box elder tree 150 feet west of the "sun" shelter in order to eliminate any possible effect of interference with the circulation of the air on account of the proximity of one or two low buildings. (See fig. 3.) In this new location the wind was as free to blow about the shelter as it usually is under an isolated shade tree, but the shelter itself never felt the direct rays of the sun, except during the winter season—October 15 to April 15—when the leaves were off and the limbs of the tree made only a thin shade. The observations, however, show no noticeable effect of the difference between the two locations. The location of the "sun" shelter was not changed during the series of readings.

Observations were begun in July, 1917, and continued until the end of February, 1920. Only the two complete years, 1918, with the "shade" shelter as shown in figure 1, and 1919, with it as shown in figure 2, are considered in this discussion, as the partial records of 1918 and 1920 throw no new light upon the subject.

Throughout the series there was a consistent tendency for the daily maximum temperatures in the "sun" shelter to range higher and the minima in that shelter to range lower than the corresponding record in the "shade" shelter. Sometimes this difference would be only a fraction of a degree but, as shown by Table 7, there were usually one or more days each month when the difference amounted to 3° or 4° and on rare occasions in summer to 6° or 7°. The differences between the daily maximum temperatures in the two shelters were usually somewhat greater than those of the minimum temperatures, as shown by the values in Tables 2 and 7, so that the heating effect on the "sun" shelter was evidently greater than the nightly interference with radiation by the tree above the "shade" shelter, and these two effects combined to make the mean daily range of temperature in the "sun" shelter from 3.6° to 4.4° greater than that in the "shade" shelter in the summer time, when the tree was in full leaf and from 0.8° to 1.8° F. greater in the winter time when the tree was bare. (See Table 8.)

As shown by Table 1, the mean monthly temperatures in the "sun" shelter regularly ranged from 0.5° to 0.9° F. higher than those in the "shade" shelter in the summer and from 0.3° to 0.9° F. lower in the winter months but, oddly enough, in both years covered by the record the annual means were only 0.1° F. apart. An examination of the monthly mean maximum and mean minimum temperatures as given in Tables 2 and 3 indicates that the excess in temperature in the summer time in the "sun" shelter was due to the fact that the direct rays of the sun during the long days were more effective in raising the temperature inside it than the radiation of the short summer nights was in cooling it. In the winter season the reverse obtained. That is, radiation at night lowered minimum temperatures in the "sun" shelter more than direct sunshine raised maximum temperatures in it compared with similar readings in the "shade" shelter, which accounts for the deficiency in mean monthly temperature in the "sun" shelter in the winter season.

From the foregoing it is evident that daily temperatures observed in a standard instrument shelter freely exposed to the sun's rays are not comparable with those in a shaded shelter, though the difference in the annual mean may be negligible. As the increasing use of free-air temperature data for research purposes demands the elimination of every possible source of error, exposure as well as instrumental, it becomes highly important either that a shelter be evolved that will eliminate the effects of isolation and radiation entirely or that special care be taken to have a uniform exposure for all shelters of the present type.

This series of observations does not, of course, settle the question of which more nearly represented free air temperatures—those in the "sun" shelter or those in the "shade" shelter—but it certainly does demonstrate the importance of giving uniform exposure to all shelters used for getting free air temperatures whether at the 200 fully equipped Weather Bureau stations or the nearly 4,500 cooperative stations. Although a short series of observations at one locality is not a sufficient basis for accurate conclusions, it appears that any *serious* studies of temperature observations will have to take into consideration the effect of the location of the instrument shelters, though possibly for ordinary compilations this may be disregarded.

TABLE 1.—*Mean temperatures.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 17.4 | 34.6 | 50.0 | 50.0 | 69.6 | 78.3 | 77.4 | 82.7 | 62.4 | 60.2 | 41.1 | 36.7 | 55.0 |
| "Shade" shelter..... | 17.7 | 34.8 | 50.2 | 50.0 | 69.2 | 77.6 | 76.6 | 82.2 | 62.2 | 59.7 | 41.4 | 37.6 | 54.9 |
| Difference.... | −0.3 | −0.2 | −0.2 | 0.0 | +0.4 | +0.7 | +0.8 | +0.5 | +0.2 | +0.5 | −0.3 | −0.9 | +0.1 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 30.7 | 34.5 | 44.8 | 54.4 | 62.6 | 74.1 | 80.6 | 77.0 | 71.2 | 55.1 | 42.2 | 25.8 | 54.4 |
| "Shade" shelter..... | 31.2 | 34.6 | 44.8 | 54.0 | 62.2 | 73.2 | 80.0 | 76.4 | 71.0 | 55.2 | 42.6 | 26.1 | 54.3 |
| Difference.... | −0.5 | −0.1 | 0.0 | +0.4 | +0.4 | +0.9 | +0.6 | +0.6 | +0.2 | −0.1 | −0.4 | +0.3 | +0.1 |

TABLE 2.—*Mean maximum temperatures.*

| | Jan. | Feb | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 29.6 | 49.5 | 66.5 | 62.4 | 81.5 | 91.9 | 90.6 | 96.8 | 76.4 | 72.1 | 48.5 | 46.8 | 67.7 |
| "Shade" shelter..... | 29.1 | 49.0 | 65.8 | 61.0 | 79.9 | 89.2 | 87.8 | 94.1 | 73.4 | 69.5 | 47.8 | 46.8 | 66.1 |
| Difference.... | +0.5 | +0.5 | +0.7 | +1.4 | +1.6 | +2.7 | 2.8 | +2.7 | +3.0 | +2.6 | +0.7 | 0.0 | +1.6 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 43.8 | 45.5 | 56.8 | 65.2 | 74.1 | 85.3 | 94.5 | 90.7 | 85.1 | 67.7 | 56.5 | 35.4 | 66.7 |
| "Shade" shelter..... | 43.5 | 45.2 | 56.1 | 64.2 | 72.2 | 82.6 | 91.8 | 88.0 | 82.9 | 66.3 | 56.1 | 35.0 | 65.3 |
| Difference.... | +0.3 | +0.3 | +0.7 | +1.0 | +1.9 | +2.7 | +2.7 | +2.7 | +2.2 | +1.4 | +0.4 | +0.4 | +1.4 |

TABLE 3.—*Mean minimum temperatures.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 5.3 | 19.7 | 33.4 | 37.6 | 57.6 | 64.7 | 64.1 | 68.6 | 48.5 | 48.4 | 33.7 | 26.6 | 42.4 |
| "Shade" shelter..... | 6.3 | 20.7 | 34.6 | 38.2 | 58.6 | 66.0 | 65.4 | 70.3 | 50.5 | 49.9 | 34.9 | 28.4 | 43.6 |
| Difference.... | −1.0 | −1.0 | −1.2 | −0.6 | −1.0 | −1.3 | −1.3 | −2.3 | −2.0 | −1.5 | −1.2 | −1.8 | −1.2 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 17.6 | 23.5 | 32.7 | 43.6 | 51.1 | 62.9 | 66.8 | 63.4 | 57.2 | 42.5 | 27.9 | 16.3 | 42.1 |
| "Shade" shelter..... | 18.9 | 24.0 | 33.4 | 43.9 | 52.2 | 68.8 | 68.3 | 64.7 | 59.1 | 44.1 | 29.2 | 17.2 | 43.2 |
| Difference.... | −1.3 | −0.5 | −0.7 | −0.3 | −1.1 | −0.9 | −1.5 | −1.3 | −1.9 | −1.6 | −1.3 | −0.9 | −1.1 |

TABLE 4.—*Maximum temperatures.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 52 | 78 | 85 | 80 | 92 | 106 | 104 | 109 | 92 | 92 | 72 | 69 | [1] 109 |
| "Shade" shelter..... | 52 | 76 | 85 | 80 | 90 | 103 | 100 | 107 | 88 | 87 | 69 | 69 | [3] 107 |
| Difference.... | 0 | +2 | 0 | 0 | +2 | +3 | +4 | +2 | +4 | +5 | +3 | 0 | +2 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 65 | 62 | 70 | 86 | 86 | 98 | 104 | 104 | 98 | 92 | 70 | [2] 68 | [2] 104 |
| "Shade" shelter..... | 66 | 61 | 70 | 85 | 84 | 95 | 100 | 101 | 96 | 91 | 69 | [2] 67 | [3] 101 |
| Difference.... | −1 | +1 | 0 | +1 | +2 | +3 | +4 | +3 | +2 | +1 | +1 | +1 | +3 |

[1] Aug. 3. [2] July 31, Aug. 6. [3] Aug. 6.

TABLE 5.—*Minimum temperatures.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | | | | | | | | | | | | | |
| "Sun" shelter.. | −18 | −16 | 15 | 20 | 30 | 49 | 52 | 48 | 30 | 32 | 12 | −3 | [1] −18 |
| "Shade" shelter | −17 | −15 | 17 | 22 | 32 | 50 | 55 | 51 | 34 | 34 | 14 | −1 | [1] −17 |
| Difference.... | 1 | 1 | 2 | 2 | 2 | 1 | 3 | 3 | 4 | 2 | 2 | 2 | −1 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | −19 | 0 | 1 | 27 | 38 | 46 | 54 | 50 | 42 | 24 | 5 | −15 | [2] −19 |
| "Shade" shelter | −18 | 2 | 3 | 28 | 40 | 47 | 56 | 50 | 45 | 25 | 7 | −13 | [3] −18 |
| Difference.... | 1 | 2 | 2 | 1 | 2 | 1 | 2 | 0 | 3 | 1 | 2 | 2 | −1 |

[1] Jan. 12, [2] Jan. 2, 3, [3] Jan. 3.

TABLE 6.—*Greatest daily range of temperature.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 44 | 52 | 49 | 45 | 40 | 39 | 39 | 45 | 42 | 43 | 35 | 34 | 52 |
| "Shade" shelter | 41 | 48 | 47 | 44 | 37 | 33 | 30 | 40 | 44 | 35 | 38 | 34 | 48 |
| Difference.... | 3 | 4 | 2 | 1 | 3 | 6 | 9 | 5 | 2 | 8 | 3 | 0 | ..... |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 49 | 43 | 42 | 42 | 37 | 36 | 41 | 42 | 46 | 42 | 42 | [a] 43 | 49 |
| "Shade" shelter | 49 | 42 | 39 | 39 | 34 | 31 | 35 | 36 | 40 | 37 | 40 | [a] 41 | 49 |
| Difference.... | 0 | 1 | 3 | 3 | 3 | 5 | 6 | 6 | 6 | 5 | 2 | 2 | ..... |

TABLE 7.—*Greatest difference between daily readings on any day.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual mean difference. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| Maximum temperatures..... | 3 | 4 | 5 | 3 | 4 | 4 | 4 | 6 | 5 | 7 | 3 | 3 | 4.2 |
| Minimum temperatures..... | 3 | 3 | 3 | 3 | 3 | 7 | 3 | 4 | 4 | 4 | 3 | 3 | 3.6 |
| 1919. | | | | | | | | | | | | | |
| Maximum temperatures..... | 3 | 2 | 2 | 3 | 6 | 4 | 4 | 4 | 6 | 4 | 4 | 2 | 3.7 |
| Minimum temperatures..... | 3 | 4 | 2 | 2 | 3 | 2 | 3 | 4 | 5 | 3 | 2 | 4 | 3.1 |

NOTE.—In each instance given in this table the maximum was higher and the minimum lower in the "sun" shelter.

TABLE 8.—*Mean daily range of temperature.*

| | Jan. | Feb. | Mar. | Apr. | May. | June | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Annual. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918. | | | | | | | | | | | | | |
| "Sun" shelter.. | 24.3 | 29.8 | 33.1 | 24.8 | 23.9 | 27.2 | 26.5 | 28.2 | 27.9 | 23.7 | 14.8 | 20.2 | 25.3 |
| "Shade" shelter | 22.8 | 28.3 | 31.2 | 22.8 | 21.3 | 23.2 | 22.4 | 23.8 | 22.9 | 19.6 | 12.9 | 18.4 | 22.5 |
| Difference.... | 1.5 | 1.5 | 1.9 | 2.0 | 2.6 | 4.0 | 4.1 | 4.4 | 5.0 | 4.1 | 1.9 | 1.8 | 2.8 |
| 1919. | | | | | | | | | | | | | |
| "Sun" shelter.. | 26.2 | 22.0 | 24.1 | 21.6 | 23.0 | 22.4 | 27.7 | 27.3 | 27.9 | 25.2 | 28.6 | 19.1 | 24.6 |
| "Shade" shelter | 24.6 | 21.2 | 22.7 | 20.3 | 20.0 | 18.8 | 23.5 | 23.3 | 23.8 | 22.2 | 26.9 | 17.8 | 22.1 |
| Difference.... | 1.6 | 0.8 | 1.4 | 1.3 | 3.0 | 3.6 | 4.2 | 4.0 | 4.1 | 3.0 | 1.7 | 1.3 | 2.5 |

## THE STANDARD ATMOSPHERE.

(Discussion.)

With the advance of aeronautics and the science of artillery, engineers and specialists in these fields have come to require a specific knowledge of the varying states of the atmosphere from the ground to very great elevations. This has led to the introduction of a conventional term commonly known as *the standard atmosphere*, which pretends to specify the normal or average condition. As is well known, the "standard atmosphere" is never found; that is to say, at no time or place do "standard" or average conditions of all of the meteorological elements at all altitudes simultaneously occur. Nevertheless it is proper, and in certain fields (especially those of aviation and ordnance) it is necessary, to adopt so-called "standard" values, and it is desirable to have these represent as closely as possible true mean values in order that corrections due to departures from these means may be comparatively small in most cases. It would be advantageous, so far as accuracy is concerned, to use at least three sets of "standard" conditions—one for summer, one for winter, and a third for spring and autumn; but this would complicate the matter, so far as practical use is concerned, and the usual custom is, therefore, to adopt one set of values only and to use this set in com-

puting a formula whose constants define the "standard atmosphere." *As already stated*, the values adopted for this purpose *should* be as nearly as possible true annual averages. These the meteorologist can furnish for many regions, principally for Europe and the United States, yet we find not infrequently "investigators" picking out a few observations here and there and spending (in effect *wasting*) much time and energy in computing formulæ for general application based thereon. An instance of this practice is to be found in a recent paper by M. Soreau,[1] in which he essays to establish "standard" free-air conditions. Unfortunately his results are based upon only *40* sounding balloon records, whereas some hundreds might have been used. Worse still, these 40 soundings are very poorly distributed as to season. There are 15 in the cold months January and February, 23 in the transitional months March to May, and only 2 in the one summer month of June, and even these 2 are in the early part of that month. It is not surprising, therefore, to find that the pressures at all heights above the surface are considerably below true annual averages.

Using his means M. Soreau evolves the following empiric equation:

$$Z = 5\ (3064 - 1.73\ P - 0.0011\ P^2)\ \log \frac{760}{P},$$

in which $Z$ is the desired altitude and $P$ the observed pressure. He states that this formula fits his mean values well, which is not surprising, since it is based upon them. It does not, however, fit any other values that have been published. Applied to those for Europe given by Dines,[2] the errors in determining $Z$ are about 1.3 per cent; applied to those for the United States,[3] the errors are nearly 4 per cent. It is not to be expected, of course, that a single formula will apply to different, widely separated localities, but a formula for use in Europe should certainly be based upon representative European data. Otherwise, the conclusions mislead those not familiar with meteorological data. In a more recent note Rateau,[4] calls attention to discrepancies in Soreau's values and those given by Lapresle for Lindenberg, and expresses the hope that further information as to average free-air conditions may be obtained. As a matter of fact there is already sufficient information for this particular purpose, so far as Europe is concerned.

Naturally, the remainder of M. Soreau's paper, in which he discusses the relations between $\lambda$ and $\mu$ ($\lambda$ being the ratio of the specific gravity at $Z$ altitude to that at the surface, and $\mu$ the corresponding ratio of pressures) is of little value, since it is based upon incomplete data.

Finally, a more acceptable discussion of the subject has been made by Prof. Pericle Gamba, who has employed a large number of observations in several countries, resulting in a reasonably close representation of the average conditions in the free air. Prof. Toussaint [5] has utilized Gamba's analysis of the meteorological data in the formulation of a proposed interallied agreement as to the law of decrease of temperature with increase of altitude. Toussaint proposes the adoption of a "law" of linear decrease of temperature with altitude, starting at a temperature of 15° C. at sea level and attaining −50° C. at an altitude of 10,000 meters. This "law" is expressed by the formula $t = 15 - 0.0065\ Z$, in which $t$ = temperature in °C. and $Z$ = altitude in meters.

Using this formula for computing the "standard" temperature for various heights, and assuming further that the atmosphere is dry and that gravity remains constant at all levels, the author quickly determines the appropriate values of pressure and density. The results are given, in abridged form, in the following table:

| Altitude above mean sea level. | Pressure. | Temperature. | Density. |
|---|---|---|---|
| *m.* | *mm.* | °C. | *kg./cu.m.* |
| 0 | 760 | 15 | 1.225 |
| 500 | 714.2 | 13 | 1.165 |
| 1,000 | 673.4 | 9 | 1.112 |
| 1,500 | 634 | 6 | 1.060 |
| 2,000 | 596.2 | 2 | 1.008 |
| 2,500 | 560 | − 1 | 0.957 |
| 3,000 | 525.7 | − 5 | 0.907 |
| 3,500 | 493 | − 8 | 0.865 |
| 4,000 | 462.2 | −11 | 0.820 |
| 4,500 | 432.2 | −14 | 0.778 |
| 5,000 | 405 | −18 | 0.735 |
| 6,000 | 353.8 | −24 | 0.660 |
| 7,000 | 307.8 | −31 | 0.588 |
| 8,000 | 266.9 | −37 | 0.525 |
| 9,000 | 230.4 | −44 | 0.467 |
| 10,000 | 198.2 | −50 | 0.413 |

Although the adopted rate of temperature decrease is arbitrary, the resulting values nevertheless agree quite well with annual means as published by various investigators for Europe and the United States. (*Cf.* references in footnotes 2 and 3.) Prof. Toussaint remarks:

> It has been found preferable to take a linear law rather than to seek an equation approximate to Prof. Gamba's curve, for the following reason:
>
> In order to define the standard atmosphere, what is needed is not an exact representation of that curve, but merely a law that can be conveniently applied and which is sufficiently in concordance with the means adhered to. By this method, corrections due to temperature will be as small as possible in calculations of airplane performances, and will be easy to calculate. The proposed law seems likely to realize such conditions.
>
> The deviation is of some slight importance only at altitudes below 1,000 meters, which altitudes are of little interest in aerial navigation. The simplicity of the formula largely compensates this inconvenience.
>
> It must be remarked, however, that since the isothermal layers seem to commence, in European regions, at an altitude of about 11,000 meters, it would be dangerous to extrapolate above that altitude.
>
> When it becomes an ordinary occurrence for airplanes to attain that altitude, it will be necessary to modify the law, but it suffices for the machines now in use.

It should be further remarked that the proposal is improperly referred to as a "law." A law is supposed to define something that is exact, within reasonable limits, whereas the actual conditions at different times and places will differ widely from this or any other assumed rate of decrease. "Standard atmosphere" is probably the best expression. It is to be hoped, though, that not even that term will be adopted, until all, or at any rate most, countries have agreed to use the same values.—*W. R. Gregg.*

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[1] Lois expérimentales des variations de la pression barométrique et du poids spécifique de l'air avec l'altitude, par Rodolphe Soreau. *L'Aérophile*, Novembre 1-15, 1919, pp. 325-342. Also in briefer form in *Comptes Rendus*, December 1, 1919, pp. 1023-1025.

[2] Characteristics of the free atmosphere, W. H. Dines, F. R. S., *Geophysical Memoirs No. 13*, Meteorological Office, London, 1919, M. O. 220c. pp. 47-76.

[3] Kimball, H. H.: On the relations of atmospheric pressure, temperature, and density to altitude. MONTHLY WEATHER REVIEW, March, 1919, **47**: 156-158.

Gregg, W. R.: Average free-air conditions as observed by means of kites at Drexel Aerological Station, Nebr., during the period Nov., 1915, to Dec., 1918, inclusive. MONTHLY WEATHER REVIEW, Jan., 1920, **48**: 1-11.

[4] A. Rateau: Variations du poids spécifique de l'air avec l'altitude en atmosphère standard. *L'Aérophile*, Mars 1-15, 1920, pp. 72-73.

[5] Draft of interallied agreement on law adopted for the decrease of temperature with increase of altitude, Mar., 1920, Issued by Ministere de la Guerre, Aeronautique Militaire, Section Technique.

## INTERVALS BETWEEN BEGINNING OF RAINFALL IN WEST AND CENTRAL FRANCE.

A letter received from Albert Jagot, of Le Mans, France, gives an account of some interesting studies on the intervals between rainfall at Nantes and Le Mans and between Brest and Le Mans. By grouping low-pressure locations and high-pressure locations he has

tabulated the number of times rainfall occurred at the two stations within 3 hours, 4 to 6, 6 to 8, 8 to 12, etc., hours. For the LOWS the table is as follows:

| LOW centered over— | Hours interval between rain beginning at Nantes and Le Mans | | | |
|---|---|---|---|---|
| | 0-3 | 4-6 | 6-8 | 8-12 |
| 1. British Isles | 38 | 12 | 2 | 11 |
| 2. Netherlands | 12 | 15 | ..... | 3 |
| 3. Norway, Iceland, Stornoway | 10 | 5 | 4 | 1 |
| 4. Brittany, Straits of Dover, Western France | 2 | 13 | 4 | 7 |
| 5. Sweden, Baltic Sea | 7 | ..... | 2 | ..... |
| | 69 | 45 | 12 | 22 |

For HIGHS the following is the result:

| HIGH centered over— | Hours interval between rain at Nantes and Le Mans | | | |
|---|---|---|---|---|
| | 0-3 | 4-6 | 6-8 | 8-12 |
| 1. Spain, Gascony | 36 | 12 | 11 | 7 |
| 2. Central Europe | 30 | 5 | 21 | 4 |
| 3. Great Britain (with LOW over North Sea) | 6 | 4 | 2 | ..... |
| 4. Southeast of Europe | 2 | 6 | ..... | 2 |
| | 74 | 27 | 34 | 13 |

It is thus seen that the shorter interval, 0 to 3 hours, seems to prevail. At the time of the rainfalls which were compared, the winds in the most cases were from NW. to SSW. Similar studies were made for the interval between Brest and Le Mans, with the following result:

| LOW centered as in— | Hours interval between rain at Brest and Le Mans | | | |
|---|---|---|---|---|
| | 0-6 | 6-8 | 8-12 | 12-15 |
| 1 above | 11 | 6 | 6 | 1 |
| 4 above | 3 | 1 | 2 | ..... |
| 5 above | 4 | 1 | 1 | ..... |
| | 18 | 8 | 9 | 1 |

| HIGH centered as in— | Hours interval between rains at Brest and Le Mans | | | |
|---|---|---|---|---|
| | 0-6 | 6-8 | 8-12 | 12-14 |
| 1 above | 9 | 4 | 6 | 1 |
| 2 above | 6 | ..... | ..... | ..... |
| 3 above | 3 | 2 | 2 | ..... |
| 4 above | ..... | 3 | ..... | ..... |
| | 18 | 9 | 8 | 1 |

Here, too, the prevailing interval is the shortest one, and the winds, says the writer, are the same as in the previous case. The distance between Nantes and Le Mans is 185 kilometers, and between Brest and Le Mans is about 420 kilometers.—*C. L. M.*

## THE MOST INTENSE RAINFALL ON RECORD.[1]

By BENJAMIN C. KADEL.

Mr. H. G. Cornthwaite's article, "Panama Rainfall," in May, 1919, MONTHLY WEATHER REVIEW, **47**: 298–320, contains in Table 1, Maximum rainfalls, a statement of the occurrence of 2.48 inches of rainfall in 5 minutes at Porto Bello, Panama, 2:07 a. m., November 29, 1911. The actual record has been kindly loaned to the Weather Bureau (see retouched photostat, fig. 1), and from it we learn that all but 0.01 inch fell in three minutes, or at a rate of 0.82 inch per minute. As this exceeds by 100 per cent the rate of 8.07 inches in 20 minutes at Curtea de Arges, Roumania, July 7, 1889, heretofore considered the world's record, it is desirable to record such facts as may have a bearing upon its validity.

The shower that includes the period under consideration fell at an excessive rate from 12:45 a. m. to 2:45 a. m., the total fall for the two hours exceeding 6 inches. The total rainfall for the 24-hour period ending at 5 p. m. was 7.60 inches by stick measurement. The 12-inch tipping bucket registering gage apparently functioned properly throughout the period, although the record for the three minutes is so blurred as to be illegible, the blurring being due to the slow clock speed rather than to instrumental failure. The actual fall during the period was determined by first correcting the legible portion of the 24-hour record on the basis of the previous performance of the gage, and in accord with accepted practice, then crediting the remainder to the excessive period. It is established by letters of inquiry, addressed by Dr. Brooks to Mr. Cornthwaite, that the gage was emptied at 5 p. m. before the rain began; that the instrument was in the hands of careful observers; that to enter both stick measurements and registration was the usual practice; that the water was regularly poured out at each observation; and that no foreign substance was found in the rain gage or in the funnel at the time the rain was measured. The record was promptly made the subject of special inquiry, and the officer in command states that in his opinion it is correct. Persons who were at work at the time remarked about the heavy rain, and low-lying ground was covered with several inches of water, drains not being capable of carrying it away as fast as it fell. Several large boulders were dislodged and washed down the hillsides, and the reservoir supplying the town with water overflowed. The record therefore appears to be well substantiated.

While the evidence supporting the validity of the record is sufficient under ordinary circumstances to warrant acceptance, it appears proper to set forth in this connection some reasons for doubting that the actual quantity of rain fell within the three minutes. The method of interpreting the record by the process of elimination means that any failure of the tipping bucket to register throughout the entire 24 hours would be credited to the three-minute period. Dr. Brooks counted 13 or 14 projections on the original record, which probably means 13 or 14 excursions of the zigzag pen, corresponding to 1.30 or 1.40 inch. The record is too blurred to be sure of more ups and downs. This agrees fairly well with the performance of a tipping bucket during an experiment at this office, during which 2.48 inches of water was poured into a similar rain-gage funnel, after which the lower end of the funnel was opened. The time required for the water to flow through the opening was 2 minutes and 15 seconds, and the tipping bucket made 194 tips during the process. The performance of the bucket was decidedly erratic, especially at first. Now, since the time occupied in discharging 2.48 through the small opening at the lower end of the funnel is nearly as

[1] Paper presented at meeting of the American Meteorological Society, Washington, D. C., Apr. 22, 1920.

great as the time occupied by the excessive rainfall record, the question is raised as to whether some foreign substance may have become lodged at the bottom of the funnel, so that the flow was practically shut off for some time preceding the record, and the accumulated pressure of the water finally forced out the obstruction, and the water all rushed through in three minutes. This interpretation of the record is strengthened by its appearance during the 17 minutes preceding, when the rain, which had been falling at a heavy rate, slackened. Another possibility mentioned by the observer in charge is that some one may have poured a quantity of water into the gage, although the chances of anyone having done so at 2 a. m. during a tropical rainstorm are remote.

Dr. H. C. Frankenfield has suggested hailstones as a possible means of closing the gage for a time.

EXTRACTS FROM CORRESPONDENCE.

In reporting the rainfall of November, 1911, at Porto Bello, Panama, Mr. John H. Poole remarked:

There was a young cloudburst at about 2:00 a. m. [Nov. 29], we were unable to properly count the amount registered.

*Poole.* 11/30/11.

Mr. C. M. Saville, on receiving the automatic record, figured by elimination that the amount had been 2.46 inches in three minutes between 2:07 and 2:10 a. m. Further information was requested from Mr. Poole, who replied as follows:

PORTO BELLO POLICE STATION,
*December 11, 1911.*

MR. C. M. SAVILLE,
*Assistant Engineer, Culebra, Canal Zone.*
(Through Chief of Police, Ancon.)

SIR: Replying to your letter of the 8th instant, relative to heavy rain at this place on the night of November 28–29th, I have the honor to state that at about 8:00 a. m. on the 29th ultimo, first-class policeman Anthony J. Lechler, #108, Zone Police, who was on duty from midnight the 28th to 8:00 a. m. the 29th, informed me that there had been an extra heavy rainfall during his tour of duty; he also called my attention to the rainfall record sheet. I examined the gage and register, found that there was nothing apparently wrong, that nothing had been tampered with so far as I could learn. I then measured the water in the tank and found the amount as recorded by me on report of the 28 29th ultimo. It is possible that some one could have poured a bucket of water into the tank, but I am of the opinion that such is not the case. In my opinion the records are correct.

Several persons who were at work at the time have remarked about the heavy rain that fell that night. The low ground in the vicinity of the machine shop, district quartermaster's office, and police station was covered with several inches of water during the hard rain, drains not being capable of carrying it away as fast as it fell.

Very respectfully,

JOHN H. POOLE,
*Corporal #18, Zone Police, Police Officer in Command.*

The following letter was received, dated Balboa Heights, C. Z., October 3, 1919:

DEAR MR. BROOKS: Replying to your inquiry regarding the maximum rainfall record at Porto Bello, the automatic record, together with copies of the correspondence on the subject, are inclosed herewith. In addition to the information contained in this correspondence, it may be stated that several large boulders were dislodged and washed down the hill sides and the reservoir supplying the town with water overflowed during this rainstorm.

The automatic record was accepted as probably approximately correct for the following reasons:

(1) The policemen at Porto Bello had always been accurate and reliable observers.

(2) The rain gage was located on the slope of a clayey hill about 100 feet back and 30 feet above the floor of the police station in a position difficult of access except thru the police station (see fig. 2).

(3) The heaviest downpour occurred at about 2.00 a. m., in the midst of a period of heavy rainfall at a time of the night when the gage could not have been tampered with except with *malicious intent*, and with considerable personal inconvenience to the perpetrator.

(4) The *variable rates* of rainfall immediately preceding and following the period of heaviest fall indicate that the funnel of the gage could not have been stopped up, causing the water to accumulate in the upper section of the gage.

It will be noted that the amount of rainfall during the period of maximum fall was determined largely by elimination, subtracting the rainfall during the remainder of the storm from the total amount collected in the gage to determine the amount during the period of maximum fall when the record was indistinct, the automatic record being corrected on account of the excessive rate of fall.

Summarizing, it would seem that this record is approximately correct, unless some one with malicious intent falsified it by pouring a quantity of water into the gage, but it seems hardly likely that anyone would get up at 2.00 a. m. in the midst of a heavy tropical rainstorm, climb a slippery clay hill back of the police station, and pour a bucket of water into the rain gage as a practical joke, and then remain forever silent on the subject to escape detection.

* * * * * *

Very respectfully,

H. G. CORNTHWAITE,
*Assistant Chief Hydrographer.*

This was followed by a letter to Mr. Cornthwaite December 2, 1919, excerpts of which follow:

* * * * *

Several of us have given it careful scrutiny, and the following questions have been raised:

1. What had been the performance of the rain gage immediately preceding these dates, i. e., how many tips did the bucket make relative to the measured amounts on other occasions when the rainfall was so heavy as the 1-inch-in-20-minutes rates found on the sheet before me? I presume that the previous performance was the basis for the corrections applied to the record at hand.

2. Was there any water in the gage not poured out at 5 p. m. the 28th?

3. What can you say as to the possibility of a slight obstruction having become lodged in the funnel for the 17 min. preceding the blurred record? This period had only 0.13 in. recorded.

4. Were there any reports of such an exceptional downpour having been noticed after the few minutes of quiet that preceded it?

I have been able to count 12 top and bottom tips, indicating 1.19 of record in the period between 2:07 and 2:10 a. m., and there seems almost certainly to be 13, and possibly 14. Unless there is some systematic error in the record as a whole, e. g., the record of 0.01 in. when, say, 0.012 fell into the bucket before each tip started, it would seem unlikely that the error of registration was as great as 1 inch in this cloudburst. An experiment made here with 2.48 poured into the funnel all at once showed some erratic action, but the water went through in 2 min. and 15 sec. and the bucket tipped 194 times. The record looks very much like the Porto Bello one.

* * * * *

Very respectfully,

CHARLES F. BROOKS,
*Meteorologist-Editor.*

The following reply came:

BALBOA HEIGHTS,
*December 16, 1919.*

MR. CHARLES F. BROOKS,
*Editor Monthly Weather Review, Washington, D. C.*
(Through Chief Hydrographer.)

DEAR MR. BROOKS: Answering your questions regarding the Porto Bello rainfall record:

1. Yes; previous performance was the basis for the corrections applied to this record. An excessive shower on November 12 showed 1.29 inches by register and 1.43 inches by stick. A shower on November 22 showed 1.50 inches by register and 1.65 by stick. It is my belief that a somewhat larger correction was applied to the November 28–29 record on account of heavier rate of rainfall.

2. No. Rainfall at Porto Bello preceding this heavy rain was light. 5:00 p. m. November 26, 0.10″ by register, 0.09″ by stick; November 27, 0.11″ by register, 0.10″ by stick; November 28, 0.08″ by register, 0.07″ by stick. It will be noted that the register and stick measurements disagree slightly, indicating that the water was drawn off and *actually measured* each day. Had it been poured back into the gage, the totals would have been progressively larger day by day, and the three days' total amounts only to 0.26 inch.

3. This is thought to be possible but not probable. Rain-gage funnels here have been obstructed several times during the past 10 years by (1) cinders, or (2) bird guano, but *in no case has the obstruction been complete* and *in no case has it cleared suddenly*. In every case that has come to our notice the water has seeped through slowly, making a record almost as regular as an unbroken sunshine record, but at a slower rate.

There was no possibility of obstruction by cinders at Porto Bello and no foreign substance was found in the rain gage or funnel at the time the rainfall was measured.

4. Unfortunately the portion of the November 29th rainfall record under consideration occurred during the night (about 2 a. m.) when the

inhabitants of the village were in bed. So far as known no one noticed the period of quiet immediately preceding the heavy downfall.

Waterspouts have been observed along both coasts in Panama. It is not known whether such a phenomenon would be likely to occur at night.

Experiments here in pouring water into the raingage funnel gave a record approximately the same as you report. We were not able, however, to count the top and bottom tips, due to the blurred character of the record.

As previously stated, the Porto Bello maximum rainfall record, *although not entirely above suspicion*, was accepted as probably approximately correct. If the blurred portion of the record is *not genuine*, the malicious pouring of a quantity of water into the raingage was thought to be the most plausible explanation.

Porto Bello has experienced some very heavy rains. The rainfall station there was not in operation from August, 1914, to December, 1918, but the following newspaper report of a heavy downpour on the night of May 4–5, 1918, illustrates the excessive character of the rainfall.

"HEAVY RAINFALL IN PORTO BELLO.

"Reports from Porto Bello are to the effect that on the 5th of May (1918), a torrential downpour occurred in that town and vicinity, causing a number of land slips on the adjacent hills and considerable damage to growing crops. All of the creeks overflowed, and the water invaded the streets of the village. Some of the houses in Porto Bello are reported to have been destroyed by the inundation. The new telephone line suffered some damage through the rushing waters having overthrown trees, which fell across the line. It is said that such a rainstorm as the village just experienced is the greatest within the memory of the oldest inhabitant. No lives were lost."—(*Star* and *Herald*.)

Respectfully,

H. G. CORNTHWAITE,
*Assistant Chief Hydrographer.*

DISCUSSION.[2]

There was considerable discussion of this paper. J. Warren Smith told of how, in a cloudburst in Ohio, in which 7 inches of rain fell in half an hour, people who were out in it said that they were almost drowned and had to hold their hands over their faces to get air. S. P. Fergusson asked if there could be such rapid condensation in the atmosphere. C. F. Brooks thought that the 17-minute period of slack rainfall preceding the cloudburst was a necessary accompaniment to such an excessive rainfall, for the rate of rainfall much greater than any possible rate of condensation indicated that there must have been strong upward currents holding the raindrops up in the air, and that therefore there must have been downward current and little rainfall about the region of up-rush. H. C. Hunter called attention to the rainfall at Guinea, Va., in which 9 or more inches fell in less than 45 minutes (MONTHLY WEATHER REVIEW, 1906, Vol. 34, pp. 406–407, 2 figs.). W. J. Humphreys elaborated on the explanation of a cloudburst outlined by Dr. Brooks (see above). "Could hail have occurred?" asked Mr. Kadel. C. F. Talman called attention to the fact that hail is known in the tropics, especially in India, and that it had been reported in the mountains of Haiti and in Jamaica. Dr. Brooks called attention to the fact that most of the Indian hail occurred in the arid and semiarid parts of subtropical northwestern India, and after raising the question as to whether the Jamaica hail was not in the mountains, stated that it appeared extremely unlikely that hail would ever fall at sea level in Panama. [*Note:* An article by H. G. Cornthwaite, on "Panama thunderstorms" (MONTHLY WEATHER REVIEW, Oct., 1919, Vol. 47, pp. 722–724) mentions the occurrence of hail in the Canal Zone on three occasions in 12 years.] Mr. Kadel said that where such intense rainfalls occur, the gages should have greater capacity in the tipping bucket.

[2] Reprinted from *Bull. Amer. Met'l Soc.* May, 1920, vol. 1, no. 5, p. 52.

## SUNSHINE AND CLOUDINESS IN THE CANAL ZONE.

By H. G. CORNTHWAITE, Assistant Chief Hydrographer.

[Balboa Heights, C. Z., Apr. 21, 1920.]

The degree of daytime cloudiness in the Canal Zone is less during the dry season than in the rainy season, but even in the dry season the sky is by no means cloudless, the average degree of daytime cloudiness being about 50 per cent of the sky obscured in the dry season and about 75 per cent of the sky obscured in the rainy season. There is not the intense unobstructed solar radiation in the Canal Zone that is experienced in dry sections of the United States. The cloudless skies so common in the semiarid sections of southwestern United States are practically unknown in the Canal Zone.

March is generally the month of minimum cloudiness in the Canal Zone, while June and November are usually the months of maximum cloudiness and least sunshine. The maximum *duration* of sunshine occurs during the dry season, usually in January, and the maximum *intensity* occurs in March or April.

The daytime cloudiness is somewhat greater in the interior and over the Pacific section than on the Atlantic side. The prevailing winds during the greater part of the year blow from off the Atlantic. These winds reach the isthmus with water vapor mostly uncondensed, and therefore not visible as clouds. In crossing in the Isthmus a large part of the water vapor carried by these winds is condensed and becomes visible as cloud, the most effective agents of condensation being the ascending air currents that develop over the excessively heated land surface and the upward deflection of the winds approaching and passing over the Continental Divide. Any increase in elevation of a mass of air, from whatever cause, results in a corresponding decrease in its temperature. When the temperature of the ascending air current has been lowered to the dew point, its invisible water vapor condenses and becomes visible as cloud.

*Night cloudiness*—No actual records are available of nighttime cloudiness, but in general the cloudiness is much greater during the daytime than at night. This is especially noticeable during the dry season, when heavy cumulus clouds form regularly during the daytime, and as regularly disappear with the approach of night.

Over the interior night cloudiness often takes the form of fogs, which are numerous during the rainy season, but which usually lift or dissipate before 8.30 a. m. Few fogs occur along either coast in the vicinity of the Canal Zone. (See fig. 2.)

During the rainy season night and early morning cloudiness is heavier along the Atlantic coast, where approximately half of the total rainfall occurs during the nighttime.

*Monthly extremes.*—The maximum monthly daytime cloudiness recorded during any one month of the past 12 years was 93 per cent at Colon in July, 1914, and the least average monthly cloudiness was 30 per cent at Balboa Heights in February, 1918.

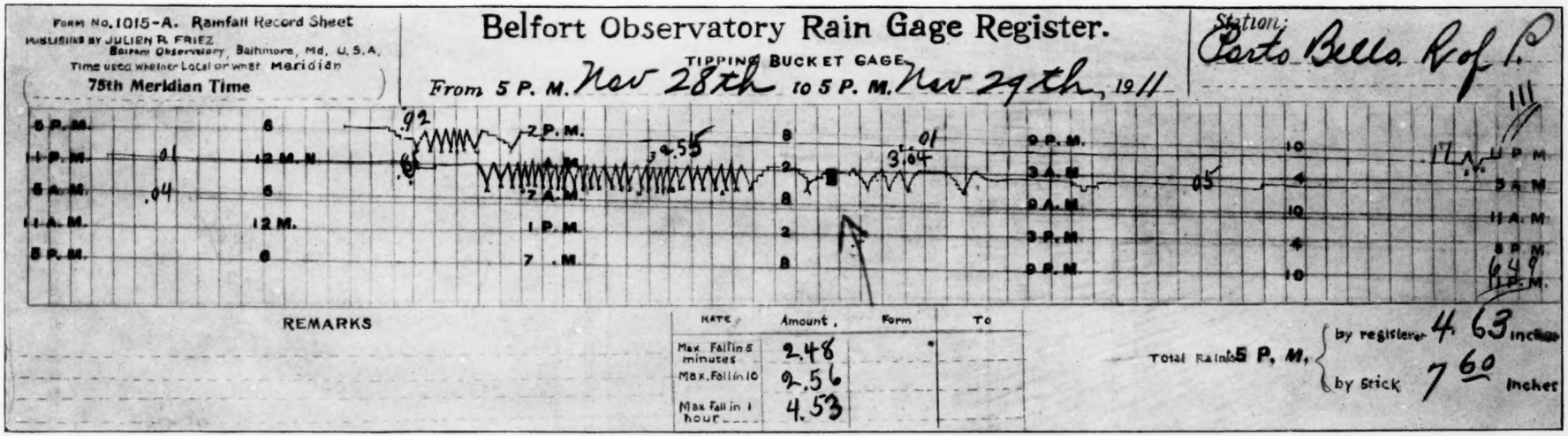

Form No. 1015-A. Rainfall Record Sheet
Published by Julien R. Friez
Belfort Observatory, Baltimore, Md. U.S.A.
Time used whether Local or what Meridian
75th Meridian Time
Belfort Observatory Rain Gage Register.
Tipping Bucket Gage
From 5 P. M. Nov 28th to 5 P. M. Nov 29th, 1911
Station: Porto Bello R of P.
REMARKS
Rate
Amount.
Form
To
Max. Falling minutes 2.48
Max. Fall in 10 2.56
Max Fall in 1 hour 4.53
Total Rainfall 5 P. M. by register 4.63 inches
by stick 7.60 inches

FIG. 1.—Retouched photostat of rainfall record showing what is believed to have been a downpour of 2.47 inches in three minutes—the most intense rainfall on record.

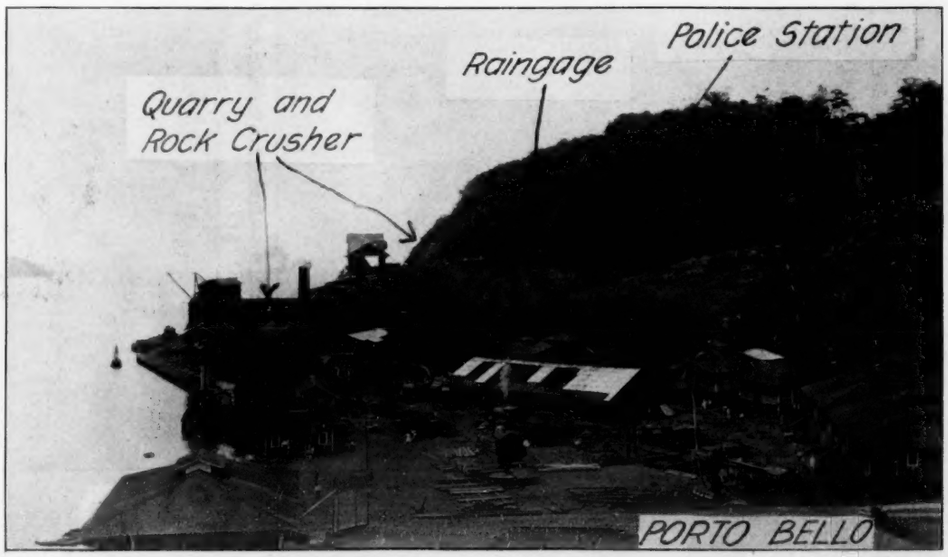
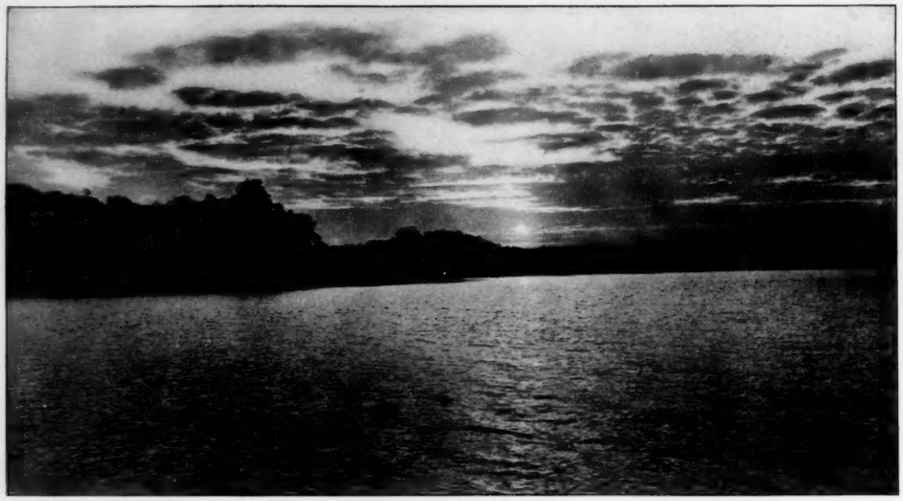


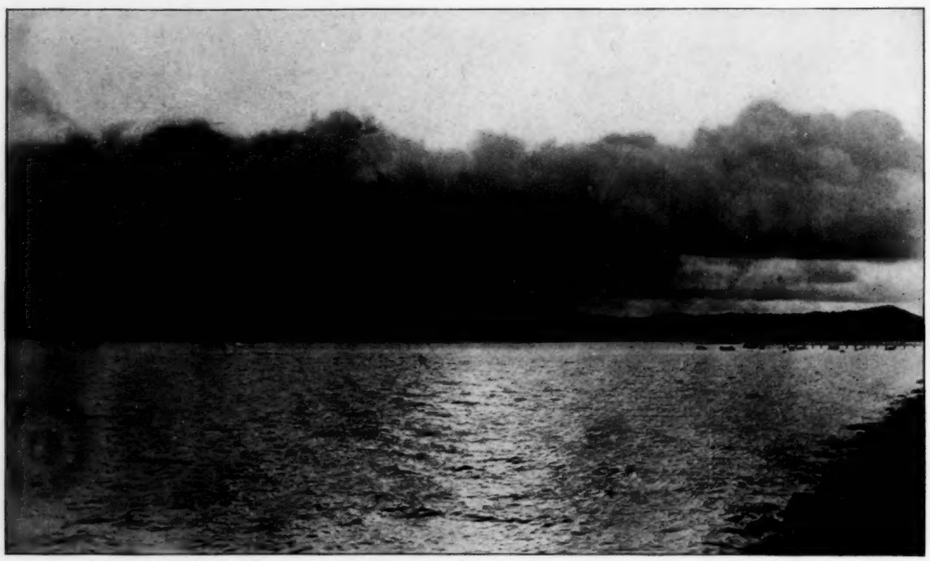

FIG. 2.—Porto Bello, Canal Zone.

[To face p. 276.



Sunrise on the Pearl Islands in Panama Bay. Showing A. Cu. and St. Cu. clouds.

Heavy cumulus clouds verging on the St. Cu. type banked low near the Pacific entrance of the canal.



Early morning fog over the Panama Canal at Culebra where the canal cuts through the Continental Divide.
[Photos by H. G. Cornthwaite.]

The maximum duration of sunshine recorded during any one month was 89 per cent of possible at Balboa Heights in January, 1915, and the least duration of sunshine for any month was 15 per cent at Balboa Heights in May, 1913.

*Prevailing cloud types.*—The cumulus form of lower clouds are most numerous during the dry season and the strato-cumulus, stratus, and nimbus forms during the rainy season. All of the common types of upper clouds are well represented throughout the year, but in the rainy season they are frequently obscured by the lower clouds.

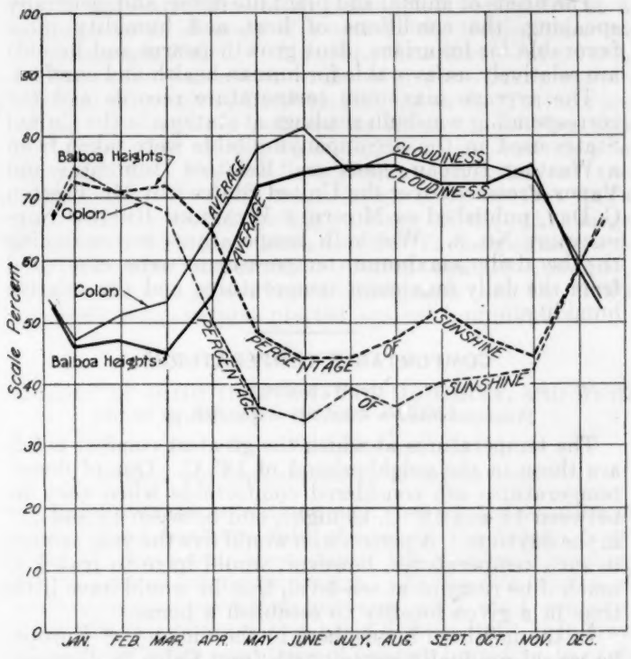



FIG. 1.—Average monthly conditions of cloudiness and sunshine in the Canal Zone.

*Comparisons.*—Compared with conditions in many sections of the United States, cloudiness in the Canal Zone is relatively heavy, especially during the rainy season; but prevailing rainstorms usually are of short duration, followed by clearing weather and sunshine and the cloudiness is so broken and intermittent that there are very few days with *no sunshine*. But when general storms visit the Isthmus (such as "Northers") there may be periods of two or three consecutive days with the sun entirely obscured.

The average number of days *without sunshine* during the past 12 years has been about 12 per year on the Pacific side and 10 on the Atlantic side. The longest consecutive period of authentic record in the Canal Zone without sunshine is about four days.[1]

The average number of clear days per year has been 36 at Balboa Heights and 54 at Colon; partly cloudy days 172 at Balboa Heights and 166 at Colon; and cloudy days, 157 at Balboa Heights and 145 at Colon. A clear day being one with average cloudiness of three-tenths or less; partly cloudy, from four-tenths to seven-tenths; and cloudy, eight-tenths or more.

The attached table and diagram show average monthly conditions of cloudiness and sunshine in the Canal Zone.

*Average monthly cloudiness and percentage of possible sunshine—Canal Zone.*

| | Cloudiness—per cent of sky obscured.[a] | | | Sunshine—per cent of possible.[c] | |
|---|---|---|---|---|---|
| | Balboa Heights, Pacific coast (13 years). | Culebra, interior (7 years).[b] | Colon, Atlantic coast (11 years). | Balboa Heights, Pacific coast (12 years). | Colon, Atlantic coast (12 years). |
| January | 47 | 49 | 46 | 75 | 73 |
| February | 51 | 50 | 47 | 71 | 71 |
| March | 53 | 47 | 45 | 68 | 72 |
| April | 65 | 63 | 54 | 50 | 65 |
| May | 78 | 77 | 72 | 36 | 48 |
| June | 81 | 81 | 74 | 34 | 44 |
| July | 74 | 80 | 75 | 39 | 44 |
| August | 77 | 78 | 75 | 36 | 47 |
| September | 75 | 77 | 72 | 40 | 52 |
| October | 75 | 79 | 72 | 41 | 47 |
| November | 73 | 80 | 75 | 42 | 44 |
| December | 60 | 61 | 58 | 59 | 59 |
| Year | 67 | 68 | 64 | 49 | 56 |
| Dry season | 54 | 52 | 48 | 66 | 70 |
| Rainy season | 74 | 77 | 72 | 41 | 48 |

[1] Based on records from automatic electric sunshine recorders. These records are not always absolutely accurate, being subject to errors due to improper adjustment of instrument, lagging, etc., but they are considered the best available.

[a] Cloudiness records are from bi-hourly eye observations.

[b] Station closed in 1914.

[c] Sunshine records are from automatic electric sunshine recorders, expressed in percentage of possible. In the Tropics possible sunshine, or the duration of daylight, varies but little from month to month, since there is little variation in the length of day and night throughout the year.

## HUMIDITY AND HOT WEATHER.

By H. G. CORNTHWAITE, Acting Chief Hydrographer.

[Balboa Heights, Canal Zone, Mar. 15, 1920.]

In a general way it is well known that conditions of humidity and wind movement are important factors in ameliorating or aggravating the depressing effects of hot weather. The maximum temperature recorded is therefore not an adequate measure of the temperature actually felt by the human body. For example, a temperature of 90° F. with high humidity and no wind seems very hot and oppressive, while the same temperature with a low degree of humidity and a fresh breeze seems relatively cool and refreshing.

For want of a better term the temperature actually felt by the human body may be called the *sensible* temperature. The reading of the wet bulb thermometer is not an exact measure of the sensible temperature, but it is the best measure available, as it represents the temperature of a moist body exposed to the breeze in process of cooling through the agency of evaporation.

The effects of humidity and wind movement on the *sensible* temperature may be explained as follows:

With a high degree of humidity the air is nearly saturated with invisible vapor, and its capacity for taking up additional moisture is small; consequently, the rate of evaporation is slow and the evaporating surface is cooled but slightly.

With a low degree of humidity the capacity of the air for taking up additional moisture is large, which favors a rapid rate of evaporation and extensive cooling of the evaporating surface.

Increased wind movement induces a more rapid rate of evaporation, with a resulting increase in its cooling effect, and also tends to cool the body by the removal of heat by conduction and convection.

Also, it is probable that high humidity has a depressing physiological effect upon the human body that is not

susceptible of exact measurement, but, as stated above, the readings of the wet bulb thermometer are considered the best measure available of the temperature actually felt by the human body.

It is very interesting to compare climatic conditions in Panama with conditions in various sections of the United States on this basis. Average daily maximum shade temperatures and the computed maximum daily sensible temperatures (wet bulb) for the month of July are presented in the following table:

| Stations. | Actual average daily maximum temperature for July. | Computed average maximum sensible temperatures for July (wet bulb). |
|---|---|---|
| | °F. | °F. |
| Balboa Heights, C. Z. | 87 | 79 |
| Cristobal, C. Z. | 84 | 78.5 |
| Mobile | 90 | 77.7 |
| New Orleans | 89 | 77 |
| St. Louis | 87 | 73 |
| Phœnix | 104 | 72 |
| Kansas City | 86 | 72 |
| New York | 82 | 70 |
| Chicago | 80 | 69 |
| El Paso | 94 | 68 |
| Fresno | 100 | 66 |
| Denver | 86 | 64 |
| San Francisco | 64 | 57 |

It should be noted that maximum *shade* temperatures only are used in the above table. No attempt is made to estimate the superheating effects of the sun on bodies exposed to direct solar radiation.

It will be seen that the *average* daily maximum July temperatures are much higher in many sections of the United States than in Panama, but the maximum *sensible* temperatures are higher in Panama than anywhere in the United States, due to the prevailing high humidity. Midsummer conditions of temperatures and humidity in the Gulf States more closely approach the conditions that prevail in Panama.

Dry season sensible temperatures in Panama are about 3° F. lower than those of the rainy season, due to the lower humidity and higher wind movement that prevails in the dry season. This explains the less oppressive character of our dry-season weather.

The high sensible temperatures and hot, humid atmospheric conditions that prevail in Panama would seem to be productive of frequent cases of sunstroke and heat exhaustion, but such is *not* the case. Canal Zone vital statistics covering the past 13 years show but two deaths from sunstroke, one in Panama and one in Colon. The total number of cases of heat exhaustion reported among the entire population of about 120,000 during this 13-year period was only 21, and none of these cases proved fatal.

While deaths from overheating are extremely rare in Panama, it is undoubtedly true that the habitual lassitude and inefficiency of tropical labor is due in large measure to the prevailing conditions of temperature and humidity.

Sufficient data are not available upon which to base an exhaustive study of this subject, but it is thought that, in general, cases of sunstroke and heat exhaustion are relatively rare both in *extremely humid* hot climates and in *arid* hot climates. It is in the *moderately humid* warm climates, such as prevail in central and eastern sections of the United States, that cases of sunstroke and heat exhaustion are most prevalent. Such cases seem to occur more frequently in large cities, probably being aggravated by the excessive radiation of heat from street paving, sidewalks, and masonry walls, and also by the lack of free air circulation in congested districts. Undernourishment and low vitality of the patients may be contributory causes.

Conditions of humidity powerfully affect plant life also. The blighting effects of the withering hot winds of Kansas that carry damage or destruction to growing crops are due more to *moisture deficit* than to *high temperatures*.

The needs of animal and plant life differ, and, generally speaking, the conditions of heat and humidity most favorable for luxuriant plant growth (warm and humid) are relatively unfavorable for human health and comfort.

The average maximum temperature records and the corresponding wet-bulb readings at stations in the United States used in the accompanying table were taken from a Weather Bureau report on "Relative Humidities and Vapor Pressures over the United States" by Mr. Preston C. Day, published as MONTHLY WEATHER REVIEW SUPPLEMENT No. 6. Wet-bulb temperatures corresponding to the daily maximum temperatures were computed from the daily maximum temperatures and the relative humidity.

## COMFORTABLE TEMPERATURES.

By W. KÖPPEN.

[Abstracted from *Das Wetter*, July–August, 1918, pp. 116–117.]

The temperatures at which the greatest comfort is felt are those in the neighborhood of 18° C. Out of doors, temperatures are considered comfortable when they lie between 14 and 18° C. at night, and between 18 and 22° in the daytime. A person who would live the year around in such temperatures, however, would have to travel so much if he remains at sea-level, that he would have little time in a given locality to establish a home.

In the northern hemisphere in the vicinity of Europe, he would gradually move north from Cairo in January, February, and March; in April he would be in Seville; in May he would go northward to Greece or Italy; in July to London, Christiania, and Helsingfors; and through the second half of the year he would retrace his journey. In the East, he would find himself in January in Calcutta, in March in Hongkong, in May in Peking and Tokyo, and thence up the coast.

Such traveling as this, however, is not practical and the person who would seek to maintain a comfortable temperature throughout the year must do it by means of ascending and descending the mountains of his vicinity.—*C. L. M.*

## OPTIMUM TEMPERATURE FOR HUMAN ENERGY.

By ELLSWORTH HUNTINGTON.

[Abstract translated from *La Nature Supplement*, Mar. 22, 1919.]

Prof. Ellsworth Huntington has published in the *Proceedings of the National Academy of Sciences* a study of this subject based on statistics.

1. If the temperature of the seasons in which the death rate is lowest is noted, it is found, in the cities of the United States as well as in those of Europe and Asia, a minimum in the springtime and in the autumn, when the mean daily temperature is in the neighborhood of 18° C.

2. If the maximum of work obtained from laborers in various factories extending from Connecticut to Florida is investigated, it is found that this maximum is obtained where the temperature oscillates about 17° C.

3. Finally, if, with a dynamometer, the muscular force of workers is measured during several seasons, it is found that the maximum efficiency occurs with a temperature of 16 to 19° C.

From these widely diverse sources of information, it appears that the optimum temperature for the human being is in the neighborhood of 18° C.

## NOTE ON DR. GRIFFITH TAYLOR'S CLIMOGRAPH CHARTS.

A note from Dr. Griffith Taylor, of Melbourne, Australia, calls attention to an unintended implication in a sentence in an abstract of a note by Sir Napier Shaw on "Climograph Charts," (MO. WEATHER REV., July, 1919, p. 494), calling attention to use of the essential principle of the climograph by Dr. John Ball before Dr. Taylor's use of it. The sentence referred to which states that this "is a fact that should be noted," was not intended to discredit Dr. Taylor's independent invention of the climograph. In fact, there is no copy of Dr. Ball's article in the Royal Society's or any of the other large libraries in Victoria. Moreover, Dr. Taylor's climograph has wet-bulb temperatures plotted against humidity, which seems to give a better climograph than Dr. Ball's dry-bulb temperatures plotted against humidity.

## EFFECT OF HIGH TEMPERATURE, HUMIDITY, AND WIND ON THE HUMAN BODY.[1]

By C. W. B. NORMAND.

[Reprinted from Science Abstracts, Apr. 30, 1920, Sect. A, §521.]

Under climatic conditions such that air temperature is above blood heat the gain of heat to the human body through convection may exceed the maximum cooling power derived from perspiration. As the rate of gain of heat through convection increases with wind velocity, while the rate of perspiring has a definite limit, it follows that, under given conditions of relative humidity, to each air temperature above blood heat there must, theoretically at least, correspond a certain critical value of wind velocity which, if exceeded, will produce a net gain of heat to the body. Under these conditions it is assumed that continued existence becomes impossible. The greater the air temperature the lower this critical wind velocity becomes.

The human body may be regarded as somewhat similar in action to a wet-bulb thermometer, which maintains its temperature by a balance between convection and evaporation. In the paper a curve is worked out by means of the wet-bulb formula, showing the conditions of air temperature and relative humidity under which a wet-bulb thermometer at blood temperature neither gains nor loses heat in a given wind velocity. Under all conditions of temperature and humidity which represent points on the diagram on one side of the curve there will be a net gain of heat, and under conditions representing points on the other side a net loss. The human body can not supply perspiration at more than a certain rate, which is analogous to a wet-bulb thermometer having a definite fixed maximum rate of supply of water. The modification in the above curve introduced by this condition is investigated. By this means the conditions of temperature, relative humidity and wind under which human life is possible are indicated with such accuracy as our present knowledge of the different conditions involved allows. As an example, with temperature at 122° F. and humidity at 8 per cent, life becomes impossible with a wind velocity above 15 meter-seconds. The fatal simoon may be explained by this means.—*J. S. Dines.*

[1] *Roy. Met'l Soc. Quart. Jour.*, Jan., 1920, **46**: 1–11; discussion, 12–14.

## THE EXTENSION OF KATA-THERMOMETER OBSERVATIONS.

[Reprinted from Meteorological Office Circular, Mar. 1, 1919, pp. 3–4.]

Dr. Leonard Hill, F. R. S., Central Staff Medical Research Committee, the inventor of the kata-thermometer, is anxious for its use to become general. The advantage of this instrument is that the readings show the combined effect of wind, temperature, sunshine, and humidity in a way comparable to the experience of the human body. The kata-thermometer is simply an ordinary thermometer of known dimensions which has to be warmed to 100°, so that the time of cooling from 100° to 95° may be observed. It is suggested that the merits of, say, Skegness and Torquay as health resorts for people of different types could be compared more satisfactorily by kata-thermometer readings than by any other observations. From the official point of view the observations are subject to the defect that the records depend so largely on exposure; in fact, they provide a measure of exposure, formulæ for estimating the speed of the wind in the immediate neighborhood from the comparison of kata-thermometer readings with the air temperature and humidity having been developed. Accordingly in publishing results it would not suffice to indicate Skegness and Torquay as the meteorological stations; the localities, sea front, inclosed garden, or what not would have to be specified. Two or three stations would really be desirable in a single health resort. It may be possible, however, to make suitable arrangements for publication if the observations become general. * * *

It should be mentioned that Dr. Hill is also asking for measurements of the temperature reached by black bodies exposed to the wind as well as to the sun or sky shine. For this purpose he uses a piece of black fur, the temperature of which is ascertained by stroking it with a small-bulbed thermometer until steady readings are obtained.

## THE IMPORTANCE OF AIR CONTROL IN HOSPITALS.

*The Modern Hospital*, for April and May, 1920 (vol. 14, pp. 271–275; 348–353), contains two articles of timely interest by Prof. Ellsworth Huntington, of Yale, dealing with the control of air in hospitals and other public buildings. The first installment treats especially of the purpose of controlling the air, and the second chiefly of the methods employed to control the air and the results that have been attained. One of the outstanding points mentioned by Prof. Huntington is the importance of small variations in the temperature, humidity, and movement of the air, in their effect upon human life.

The most important atmospheric factors are temperature, humidity, purity, movement, and variability. In most ventilating systems, however, the most attention is paid to the question of temperature and that usually to the end of producing constant temperature. The importance of humidity is recognized, also, but it is only a perfunctory recognition and, as a rule, the steps taken to control the humidity are entirely inadequate. Purity is easily controlled, partly because nature is constantly striving to produce pure air, and partly because artificial contamination by dust is easily prevented. Movement and variability are often neglected because they are frequently construed to mean drafts and hence colds. But experiment has proved that, with all other conditions the same, the patient who spends his time where the air can move over him in variable gusts with consequent short-period variations of temperature stands better chance of

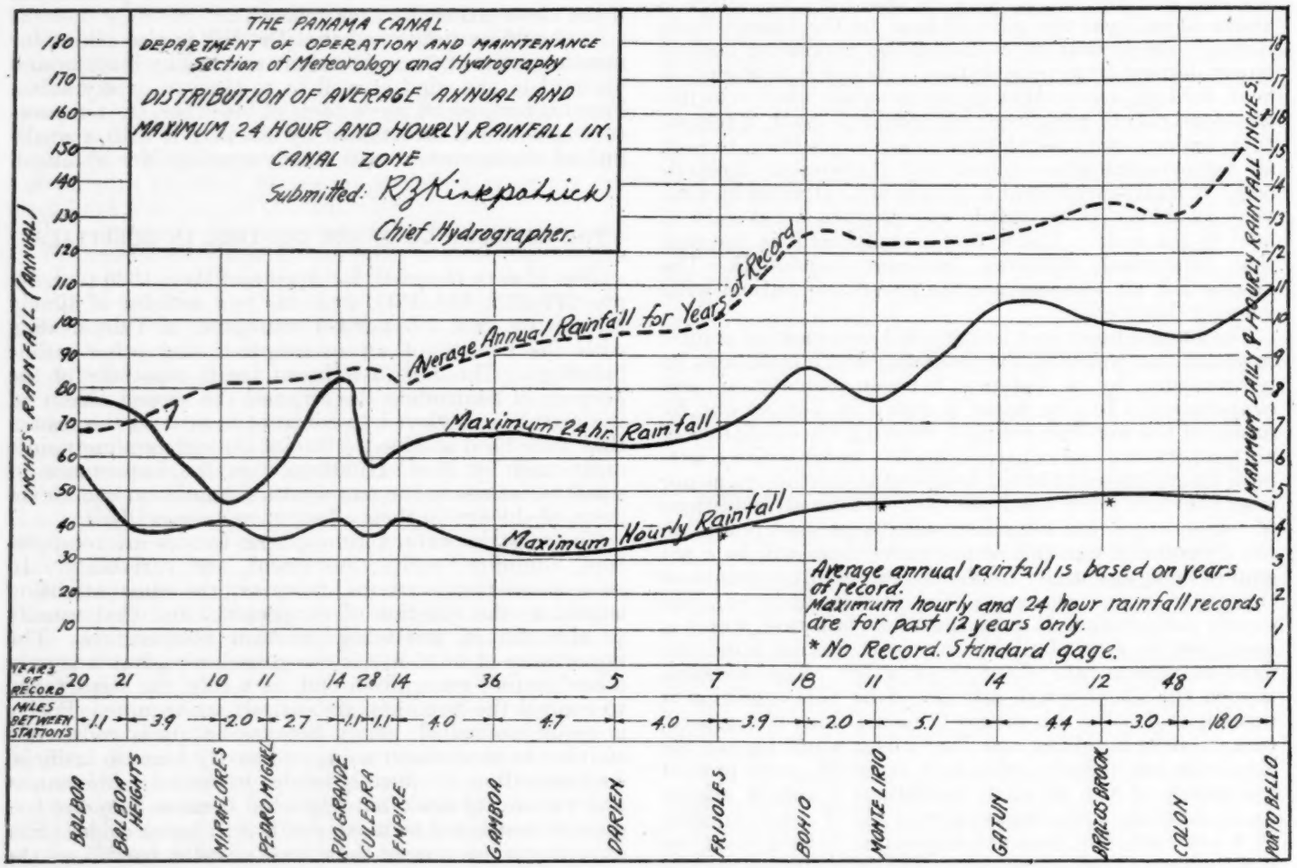
recovery than one who is shielded by glass from these irregularities.

The most satisfactory conditions are those in which the mean daily temperature is about 64° F. Night temperatures in hospitals do not, ordinarily, go low enough to give this mean. But were the air properly humidified temperatures as low as 58° would not feel cold. Differences, as mentioned above, as small as 5° F. in the mean temperature may mean a difference of 5 per cent in the hospital death rate, while differences of only 10 per cent in humidity at low temperatures may influence the death rate by from 3 to 5 per cent. The question of variability of temperature has been studied in schools, and it was found that in rooms with the supposedly ideal conditions of constant temperature and ventilation the absences attributable to respiratory diseases is 30 per cent more than those where the windows were occasionally opened. In summing up the first article, Prof. Huntington says that if attention to the correct temperature will reduce the death rate by 5 per cent, humidity by another 5 per cent, purity by 2 per cent, movement and variability 3 per cent (these figures are thought to be conservative) it would be possible to decrease the deaths by 200,000 in the United States each year. But if only one-tenth of this number could be saved, namely, 20,000 lives, it is obvious that the effort expended at air control is well worth while.

How can these ideal conditions be produced artificially? Nearly all the devices for heating and ventilating in use at present are unsatisfactory from the standpoint of one or more of the features mentioned above. In a few public buildings attempts have been made to control temperature and humidity scientifically. An example is the Boston Art Museum, in which these conditions are carefully maintained for the preservation of the art objects. Attention has been given to the question in factories because of the value to materials, but all too little attention has been paid the question in hospitals, even those which are most elaborately equipped.

These facts are a terrible reflection on our civilization. We have found out just what sort of air is needed not only for works of art, but for movie films, silk dresses, woolen coats, and cotton sheets. We make humidifying machines that enable our cigars to be rolled without cracking and our candies smoothly coated with chocolate. Our materialistic civilization spends millions of dollars in perfecting things, mere *things*, many of which are sheer luxuries. Yet when it comes to people, we have had no success as we have had with things. We have tried to produce the right conditions in schools, hospitals, and other buildings, but we have never carried on any such prolonged and patient experiments as have been tried by the makers of cigars and candy. If we should succeed with people as well as we have succeeded with things, the world's health and happiness would be improved incredibly. We can succeed if only we will try. Shall we not, then, enter upon this supremely worth-while effort?

These articles present another of the almost unlimited phases of the application of meteorology to the affairs of life, and from the great influence of small variations of the atmospheric conditions upon health, this field must be recognized at once as being one which can be no longer neglected.—*C. L. M.*


THE PANAMA CANAL
DEPARTMENT OF OPERATION AND MAINTENANCE
Section of Meteorology and Hydrography
DISTRIBUTION OF AVERAGE ANNUAL AND MAXIMUM 24 HOUR AND HOURLY RAINFALL IN CANAL ZONE
Submitted: R.Z. Kirkpatrick
Chief Hydrographer.
INCHES - RAINFALL (ANNUAL)
MAXIMUM DAILY & HOURLY RAINFALL INCHES
Average Annual Rainfall for Years of Record
Maximum 24 hr. Rainfall
Maximum Hourly Rainfall
Average annual rainfall is based on years of record.
Maximum hourly and 24 hour rainfall records are for past 12 years only.
* No Record. Standard gage.
YEARS OF RECORD 20 21 10 11 14 28 14 36 5 7 18 11 14 12 48 7
MILES BETWEEN STATIONS 1.1 3.9 2.0 2.7 1.1 1.1 4.0 4.7 4.0 3.9 2.0 5.1 4.4 3.0 18.0
BALBOA
BALBOA HEIGHTS
MIRAFLORES
PEDRO MIGUEL
RIO GRANDE
CULEBRA
EMPIRE
GAMBOA
DARIEN
FRIJOLES
BOHIO
MONTE LIRIO
GATUN
BARROS BROCK
COLON
NOMTO BELLO

## AGRICULTURAL METEOROLOGY.

J. WARREN SMITH, Meteorologist.
[Weather Bureau, Washington, D. C., June 1, 1920.]

*Definition.*—Agricultural Meteorology in its broadest sense is "Meteorology in its Relation to Agriculture."

*Historical.*—The effect of the weather upon crop growth was early recognized, and in 1806 the Hon. Simeon De Witt, of Albany, N. Y., read a memoir on "Climate in its Relation to Agriculture" before the American Agricultural Society in New York City.

On April 29, 1817, Josiah Meigs, Commissioner of the General Land Office, issued a circular soliciting meteorological records and phenological observations by the registrars of the respective land offices.

In 1819 the Surgeon General of the Army established a system of meteorological observations at the Army posts.

In 1825 the regents of the University of the State of New York directed that meteorological observations be made at each of the academies under their supervision.

In 1837 the Franklin Institute and the State of Pennsylvania began cooperation in the establishment of meteorological stations in each county in the State. The first special appropriation of public money for the collection of weather data in this country was made when the legislature of Pennsylvania granted $4,000 to the Franklin Institute.

The first official action of the United States in the study of weather conditions was made by Congress in 1842 in the appointment of Prof. J. P. Espy as meteorologist in the United States Government.

The present United States Weather Bureau was inaugurated by an act of Congress on February 9, 1870, authorizing the Secretary of War to organize a meteorological service throughout the United States. In 1872 the appropriation bill, in addition to the money for the work of the Signal Corps for the prediction of storms on the seacoast, provided for "such additional stations, reports, and signals as may be found necessary for the benefit of agricultural and commercial interests."

The Iowa State Weather Service was established in 1875, the Nebraska Service in 1878, Missouri State Weather Service in 1877, and the Ohio Meteorological Bureau in 1882. By 1891 a special weather and crop service was in operation in nearly every State.

The publication of Weather and Crop Bulletins was begun in May, 1887.

On July 1, 1891, all the meteorological work of the Signal Service was transferred to the Department of Agriculture and the present United States Weather Bureau was put into operation. Since this transfer, the work of the Weather Bureau in its relation to Agriculture has developed steadily. Special services have been established for the direct benefit of agriculture, such as the Corn and Wheat, Cotton, Sugar and Rice, Cattle, Tobacco, and Fruit Region Services. Special forecast and warning services have been inaugurated for tobacco, fruit, and truck growers; alfalfa and rice harvesting; fruit spraying, alfalfa seed harvest, and sheep shearing and lambing interests.

The present Division of Agricultural Meteorology was established as a new division in the Weather Bureau on February 23, 1916, and the work of the Bureau relating particularly to agriculture was placed under its supervision. The National Weather and Crop Bulletin has been developed to show the weather from week to week, and its effect upon the growing crops, and studies are being made to find the most critical periods of growth of the various crops and the weather most affecting them. Detailed temperature and moisture surveys are being carried on in citrus and deciduous orchards to determine the distribution of damaging weather factors, the effect of orchard heating on the temperature, and the part that radiation plays in temperature variations and fruit protection. Valuable studies in the forecasting of minimum temperatures have been published and equations evaluated from the knowledge of the moisture in the atmosphere in the afternoon and its relation to the temperature variations during the following night.

*The future.*—The writer believes that there are certain well defined and determinable periods, usually comparatively short, in the growth of most crops when the weather has a particular, favorable or unfavorable, effect upon the yield. Also that there are three definite methods for ascertaining the limits of these periods and the weather factor or factors having the greatest effect.

One of these methods is properly called the laboratory method wherein all factors affecting growth can be controlled. This problem is one that many ecologists and plant physiologists are at work on, and valuable data have been evolved. Livingston, Shreve, Briggs, Shantz, McDougal, Lehenbauer, and others have contributed to these studies.

The second method calls for a long series of field observations with careful and detailed meteorological and growth records. Many experiment station and other officials are already at work in this direction and are producing valuable results. One of the most important studies recently published is entitled "Effect of the Relative Length of Day and Night and Other Factors of the Environment on Growth and Reproduction in Plants," a contribution from the Bureau of Plant Industry, United States Department of Agriculture, by W. W. Garner and H. A. Allard, and is found in the Journal of Agricultural Research for March 1, 1920.

Another plan based upon phenological records and periodical phenomena in general has received attention in Europe for many years.

Within recent years this branch of science has been systematized for direct application to agricultural problems by Dr. A. D. Hopkins, of the Bureau of Entomology, United States Department of Agriculture, who has determined that the variation in dates of periodical events and the altitude of geographical distribution with variations in geographical position is in accordance with natural law, which he has designated and defined as the Bioclimatic Law.[1] According to this law the rate of variation in the dates and periods of natural phenomena and farm practice with variations in latitude, longitude, and altitude is governed in a sufficiently definite manner to form a reliable basis for predicting the dates and periods of seasonal events for any place in the United States. The general reliability of this method of prediction has been demonstrated in the case of seeding and harvest time for winter wheat, as fully described in the publication referred to.

Plans were started early in 1916 for the inauguration of systematic observations of this character at agricultural experiment stations in different parts of the United States. An interbureau committee was appointed in the

[1] Periodical events and natural law as guides to agricultural research and practice. Mo. WEATHER REV. SUPPLEMENT No. 9, May 1, 1918, pp. 5–42.

Department of Agriculture to consider methods, records, etc. This committee considered the whole matter carefully and, after interruption by the war, finally recommended the establishment of 12 regional agricultural meteorological stations in the principal corn, cotton, wheat (winter and spring), and potato districts.

The fact was recognized that similar stations were established in Russia in 1896, where, in 1912, complete records were being made at 81 different points. The Canadian meteorological service recognized the great importance of such stations and had, in 1915, located them at 14 different experiment farms in different sections of the country.

The Royal Meteorological Society in England has collected systematic phenological data since 1875, and similar work has been done in nearly all European countries. A division of agricultural meteorology was established in Brazil in 1910, in Germany in 1911, and in France in 1912.

It is believed that the United States, with its splendid Weather Bureau organization and well-established chain of Experiment Stations, should not be behind these other countries in putting this needed study of weather and crops on a real scientific basis with systematic observations and records. Funds were requested for this purpose in the last estimate, but the appropriation was not allowed by the congressional committees. It is hoped that better success will be had with the next Congress.

The third method of ascertaining the critical period of growth is by correlating past records of weather and crop yields. Meteorological and crop yield data are available in some States for a period of 50 or more years and a number of studies have been published. Some of the most important ones appear in the list given below and a number of men have similar studies in hand. The field is large and much material is available. The writer is satisfied that the problem is one for higher mathematics and that it is worthy the attention of the best trained men in the country.

The American Meteorological Society can well encourage studies that will have such a far-reaching effect on agriculture as these promise.

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Relation of weather to the amount of cotton ginned during certain periods. Mo. WEA. REV., Jan., 1917.
A correlation of weather conditions and the production of cotton in Texas. Mo. WEA. REV., Feb., 1915.

**Moore, H. L.**
Forecasting the yield and price of cotton. Macmillan Co., N. Y.

**O'Connor, A. J.**
Relation of weather to yield of winter wheat in Manitoba. Mo. Bul. of Agric. Statistics, Ottawa, Canada, Apr., 1918.

**Root, C. J.**
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**Seeley, D. A.**
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**Smith, J. Warren.**
Effect of weather upon the yield of corn. Mo. WEA. REV., Feb., 1914.
Effect of weather upon the yield of potatoes. Mo. WEA. REV., May, 1915.
Effect of snow on winter wheat in Ohio. Mo. WEA. REV., Oct., 1919.


Other recent studies bearing on the general subject of the effect of weather and climate upon vegetation and farm management are indicated in the following list:


MONTHLY WEATHER REVIEW.
**Alter, J. Cecil.**
Alfalfa seed growing and the weather in Utah. (May, 1919.)
**Hopkins, A. D.**
Periodical events and natural law as guides to agricultural research and practices. (The Bioclimatic Law.) (Supplement 9.)
**Kincer, J. B.**
Daytime and nighttime precipitation and their economic significance. (Nov., 1916.)
Relation between vegetative and frostless periods. (Feb., 1919.)
The seasonal distribution of precipitation and its frequency and intensity in the United States. (Sept., 1919.)
Sunshine in the United States. (Jan., 1920.)
Temperature influence on planting and harvesting dates. (May, 1919.)
**Reed, W. G., and Tolley, H. R.**
Weather as a business risk in farming. (June, 1916.)
**Stine, O. C., and Baker, O. E.**
Climate of the cotton belt. (July, 1919.)
**Smith, J. Warren.**
Cultivation does not increase the rainfall. (Dec., 1919.)
Predicting minimum temperatures from hygrometric data. (Supplement 16.)

*Department of Agriculture Yearbook.*
**Baker, O. E., Brooks, C. F., Hainsworth, R. G.**
Graphic summary of seasonal work on farm crops. (Separate 758, 1917.)
**Smith, Middleton, Baker, O. E., Hainsworth, R. G.**
Graphic summary of American agriculture. (Separate 681, 1915.)
**Finch, V. C., Baker, O. E., Hainsworth, R. G.**
Graphic summary of world agriculture. (Separate 713, 1916.)

*Department of Agriculture Publications.*
**Finch, V. C., and Baker, O. E.**
Geography of the world's agriculture. 1917.

*Journal of Agricultural Research.* Dept. of Agric., Washington, D. C.
**Dorsey, M. J.**
Relation of weather to fruitfulness in the plum. (Vol. XVII, No. 3.) [Abstr., p. 285, below.]

*Agricultural Experiment Station* Bulletins.
**Alter, J. Cecil.**
Alfalfa seed growing and the weather. (Bul. 171, Logan, Utah.)
**Baker, O. E., and Whitson, A. R.**
Climate of Wisconsin and its relation to agriculture. (Bul. 223, July, 1912.)
**Spafford, R. R.**
Effect of climate and soil upon agriculture. (Univ. Studies, Lincoln, Nebr., Feb., 1916.)

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**Thompson, H. C.T**
Home gardening in the south. (No. 934, 1918.)
**Young, Floyd D.**
Frost and protection from damage by it. (No. 1096, 1920.)

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**McLean, Forman T.**
Preliminary study of climatic conditions in Maryland as related to plant growth. (Special Pbn. Md. Wea. Serv., Vol. IV, Pt. 1A. Also Phys. Res. No. 2, 1917.)
**McLean, Forman T.**
Relation of climate to plant growth in Maryland. (Md. Wea. Rev., Feb., 1915.)

*American Geographical Society, New York City.*
**Arctowski, H.**
Corn crop in the United States. (Vol. XLIV, Oct., 1912.)

*Society for Promotion of Agricultural Science*, Wash., D. C.
**Voorhees, J. F.**
Relation of meteorological study to more logical systems of cropping and to crop production. (Proceedings, 1912.)

*Scientific Monthly.*
**Hopkins, Andrew D.**
The bioclimatic law as applied to entomological research and farm practice. (June, 1919, pp. 496–513.)

*Journal Washington Academy Sciences.*
**Hopkins, Andrew D.**
The bioclimatic law. (Vol. 10, Jan., 19 1920, pp. 34–40.)

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**Adams, J.**
Quantitative study of climatic factors in relation to plant life. (Transactions, Series III, Vol. X, 1916.)

*The Macmillan Co.*
**Smith, J. Warren.**
Agricultural meteorology, textbook. (To be published during summer, 1920.)

*Royal Meteorological Society, London, England.*
**Ward, R. deC.**
The larger relations of climate and crops in the United States. (Quarterly Journal, Jan., 1919.)

*Dept. of Agriculture, Ottawa, Canada.*
**Brounoff, P.**
Some considerations on the organization of the agricultural meteorological service. (Bul. Foreign Intelligence, April, 1916. Office of Can. Commis. of Internat. Inst. of Agric.)

*Agricultural Journal of India, Calcutta.*
**Howard, Albert.**
The influence of weather on the yield of wheat. (Vol. XI, Part 4, Oct., 1916.)

## ABSTRACTS, REVIEWS, AND NOTES.

### *Maxwell Hall, 1845–1920.*

Meteorologists of the world have read with keen regret the news of the death of Maxwell Hall, in Kingston, Jamaica, on February 20, 1920. Mr. Hall's 75 years of life were spent in England and Jamaica. He was born at Cheltenham, England, in 1845 and educated in private schools and later in King's College, London and Pembroke College, Cambridge, where, in 1871, he was graduated as Wrangler. In 1872 he moved to Jamaica, where he erected a private astronomical observatory and began scientific work. He was appointed Government meteorologist in 1880, a position which he held until his death. While he was of a retiring disposition, this quality did not serve to diminish his prominence in the public life. The death of Mr. Hall came unexpectedly, for, while he had not been been enjoying the best of health for some time, his friends had universally held hopes of his early return to health. His cooperation with the United States Weather Bureau in communicating hurricane warnings has been greatly appreciated, and many will remember his efforts to organize and perfect a system of storm-warnings in the West Indies. He has published many articles on hurricanes, earthquakes, and other scientific subjects in the journals of the United States, England and Jamaica.

### *Dr. J. G. Bartholomew, 1860–1920.*

[Abstract from Nature, London, Apr. 22, 1920, pp. 238–239.]

Dr. Bartholomew, one of the leading cartographers of the world, died suddenly April 13, 1920, at Cintra, Portugal, at the age of 60. He was a native of Edinburgh, where he received his education in the high school and at the University of Edinburgh. As a young man he entered the business (map publishers) founded by his grandfather. At the age of 29 he succeeded his father as head of this firm, which since 1889 has been known as "The Edinburgh Geographical Institute."

Early in his career he devised the method of representing topographical features by the system known as "layering," which has made the Edinburgh Geographical Institute celebrated throughout the world, and is now copied in all other cartographical establishments. It merely consists of distinctive colors, tints, or shades between successive contours on a contoured map.

In 1899 Dr. Bartholomew published "The Atlas of Meteorology," a work of immense labor with several original features, which shows even more stirringly his zeal for scientific geography, and amply justifies the motto he had adopted, "Amore et labore."

Despite his great cartographical labors he found much time to take active part in numeorus scientific societies. In his private life he was held in the highest esteem by all who knew him.—*Geo. G. Chisholm.*



### THE PHYSICS OF THE AIR.

With the recent publication in the *Journal of the Franklin Institute* of a paper in two installments on "Factors of Climatic Control," Dr. W. J. Humphreys has completed a series of papers that he has been publishing for more than two years in the journal above mentioned on the general subject of "Physics of the Air." It is expected that this work will soon be issued in book form. No first-rate comprehensive book on meteorology written from the standpoint of the physicist exists at present in any language, and there is perhaps no more striking gap in the literature of science. Dr. Humphreys's book will go a long way toward filling this gap. It is especially remarkable for the amount of skill and labor the author has devoted to checking, verifying—and in many cases discrediting—doctrines and ideas that have heretofore been passed on from one meteorological writer to another without critical examination.—*Scientific American*, New York, June 19, 1920, page 669.

### THE APRIL 22 MEETING OF THE AMERICAN METEOROLOGICAL SOCIETY.

*The Bulletin of the American Meteorological Society* for May, 1920, pages 48–55, contains a full account of the papers and discussions presented before the American Meteorological Society which met in Washington, D. C., on April 22, 1920. The sessions, one in the morning and one in the evening, were held at the Central Office of the Weather Bureau. The attendance, 40 to 50, was very good, amounting to the combined attendance at the two previous meetings in St. Louis and New York City.

The morning session was opened by an informal address of welcome by Prof. C. F. Marvin, Chief of the Weather Bureau. Of his address, the *Bulletin* says:

He discussed the opportuneness of the organization of the society at this time, when many outside interests, awakened to the value of meteorology by its applications in the war, were now seeking to apply weather knowledge more thoroughly to peace-time pursuits. The

society will be instrumental in effecting such extensions of meteorological applications, for it will bring together various groups. The signs indicate that commercial and industrial institutions will demand meteorologists for their staffs. Through the society the teachers of meteorology, now well represented in its membership, can be led to appreciate and to prepare for this rising demand for a widespread general knowledge of weather processes and for special training on the part of a few. The biggest problem before us is forecasting the weather. One present difficulty is to get away from empirical methods. This organization can do a great deal by farming out various projects among the fellows and members whether or not they may be in governmental meteorological services.

The scientific program comprised 15 papers, of which one was read in abstract and another by title only. The program follows, together with references to the MONTHLY WEATHER REVIEW, where the papers or abstracts of them will appear or have appeared:

Temperature scales and thermometer scales. E. W. Woolard. (This REVIEW, pp. 264–270.)
Shall we adopt a half-degree absolute centigrade scale instead of the Fahrenheit? Charles F. Marvin.
The physics of the aurora. W. J. Humphreys. (*Abstract* probably in June REVIEW.)
The auroras of March 22–25, 1920. Herbert Lyman. (Probably in June REVIEW.)
The most intense rainfall on record. B. C. Kadel. (This REVIEW, pp. 274–276.
New aerological apparatus. S. P. Fergusson. (Probably in June REVIEW.)
Temperatures versus pressures as determinants of winds aloft. W. R. Gregg. (This REVIEW, p. 263.)
Daily wind charts for stated levels. C. LeRoy Meisinger. (This REVIEW, pp. 251–263.)
Cloud base altitudes as shown by disappearance of balloons and kites. O. L. Lewis. (Probably July REVIEW.)
Cloud nomenclature. Charles F. Brooks. (Probably July REVIEW.)
Some meteorological observations of a bombing pilot in France. Thomas R. Reed. (April REVIEW, pp. 216–217.)
Project for local forecast studies. R. H. Weightman. (March REVIEW, pp. 154–155.)
Climatic conditions in a greenhouse as measured by plant growth. Earl S. Johnston. (*Abstract*, April REVIEW, pp. 215.)
Modifying factors in effective temperature. Andrew D. Hopkins (April REVIEW, pp. 214–215.)
Relation of rainfall to the grazing capacity of ranges. J. Warren Smith. (Probably June REVIEW.)

## METEOROLOGICAL EXHIBIT BEFORE THE ROYAL SOCIETY.

A note in *Nature* (London), May 20, 1920, pages 373–376, tells of the various exhibits displayed upon the occasion of the Royal Society's Conversazione on May 12. The Meteorological Office contributed the following exhibit:

New instruments and diagrams: (1) Land aneroid and sea aneroid. (2) Barometer and micrometric adjustment. (3) Two similar synchronous charts and the weather of the following 15 days. (4) Normal weather on the Cairo to Cape route. (5) Charts of the average distribution of rainfall, cloudiness, and temperature over the Northern and Southern Hemispheres in January and July. (6) Map of the annual rainfall in the English Lake District. (7) Records of the magnetic disturbance of March 23–24, 1920, and photographs of aurora for height measurements. (8) Frequency of thunderstorms on the route between England and Australia and at selected stations in Africa and South America. (9) The flow of air over Kew Observatory, Richmond, during the last three years.

## THE INTENSITY OF NOCTURNAL RADIATION AT HIGH ELEVATIONS.

By A. BOUTARIC.

[Abstracted from Comptes Rendus, Paris Acad., May 17, 1920, pp. 1195–1196.]

The author has shown in his previous work [1] that the intensity of notcurnal radiation, $r$, may be expressed as a function of the absolute temperature of a black radiating surface and the vapor pressure in its immediate vicinity, as follows:

$$r = \pi\sigma\, \theta_0^4\, F(f_0),$$

in which $\pi\sigma$ is a constant, depending upon the total of directions in which the surface is radiating; $\theta_0$, the absolute temperature, and $f_0$, the vapor pressure.

Work which was conducted at the Pic du Midi (2,859 meters elevation) between August 14 and 24, 1919, when compared with the results obtained at Montpellier (practically sea-level) in 1913, 1914, and 1915, leads to the conclusion that the value of $r$ is independent of the altitude when the conditions of temperature and vapor pressure are the same. This is shown in the following table:

TABLE 1.

| Date. | Time. | $t_0$ | $f_0$ | $r$[1] | $F(f_0)$. | |
|---|---|---|---|---|---|---|
| | | | | | Pic du Midi. | Montpellier. |
| | *h. m* | *°C.* | *Mm.* | | | |
| Aug. 11 | 20 24 | 11.2 | 4.8 | 0.161 | 0.321 | 0.300 |
| 14 | 21 00 | 11.3 | 5.6 | 0.138 | 0.275 | 0.284 |
| 16 | 21 00 | 9.8 | 2.3 | 0.170 | 0.346 | 0.362 |
| 17 | 21 00 | 8.0 | 2.1 | 0.168 | 0.351 | 0.368 |
| 18 | 21 15 | 7.4 | 5.4 | 0.158 | 0.333 | 0.292 |
| 19 | 21 00 | 10.1 | 4.2 | 0.154 | 0.312 | 0.312 |
| 22 | 21 00 | 7.0 | 3.4 | 0.139 | 0.294 | 0.330 |
| 23 | 21 00 | 7.9 | 1.9 | 0.154 | 0.322 | 0.374 |
| 24 | 20 50 | 8.0 | 3.4 | 0.150 | 0.313 | 0.330 |

[1] Gm. cal./sq. cm./min.

—*C. L. M.*

## THE INFLUENCE OF THE VARIATION OF THE BAROMETRIC PRESSURE ON THE MICROBIAL DROPLETS IN SUSPENSION IN THE ATMOSPHERE.

By A. TRILLAT.

[Abstracted from Comptes Rendus, Paris Academy, vol. 170, pp. 538–540, Mar. 1, 1920.]

The atmosphere, especially in the vicinity of inhabited regions, contains numerous microbe-bearing droplets projected into the air in the acts of speaking and breathing.

Laboratory experiments have shown that a sudden decrease in the air pressure accelerates the fall of such droplets, through the increase of their weight brought about by condensation upon them as a result of the cooling. A slow decrease of pressure produces but a limited effect. Other factors, such as the purity, relative humidity, etc., of the air also affect the result.

In the light of such experiments it is surmised that a rapid fall in the barometric pressure would precipitate the invisible microbial droplets in the atmosphere; at the same time such a depression would liberate gases from the soil which contribute to the vitality of the organisms; hence the effect of barometric fluctuations on the vitality of the germs in the atmosphere, their concentration in the lower strata, and their precipitation upon the soil may be an important factor in the variation of the bacteriological composition of the atmosphere.—*E. W. W.*

## WIRELESS WEATHER REPORTS OF THE METEOROLOGICAL OFFICE.

[Reprinted from *Nature*, June 10, 1920, p. 465.]

In the *Meteorological Magazine* for May a notice is given of the circulation of forecasts by wireless telegraphy from collective weather reports for London and southeast England. Hourly reports of meteorological information prepared by the Forecast Service of the Meteorological

[1] Boutaric, A.: *Thèse*, Paris, 1918 (pages following 138.)

Office are sent out from the wireless station of the Air Ministry. The message is given in code form, which is practically the same as that prescribed in Annex G of the "Convention relating to International Air Navigation," Paris, 1919. The forecasts, which are being issued eight times a day, are based on observations taken about half an hour before the time of issue. Detailed explanation of the code can be obtained on application at the Meteorological Office. A new device is also mentioned for making the meteorological reports rapidly available to the public. A large weather map is exhibited daily at the Air Ministry in one of the front windows on the ground floor of the Empire House, Kingsway. All the principal reporting stations in the British Isles, as well as a few neighboring Continental ones, are marked on the chart, which is on the Mercator projection, and is 10 feet high and 6 feet wide. The information on the chart is changed at about 3 h., 8 h. 30 m., and 14 h. 30 m. G. M. T., the data exhibited referring to observations made at 1 h., 7 h., and 13 h. G. M. T. * * *

## ON THE APPLICATION OF CIRRUS TO THE FORECASTING OF WEATHER.

By GABRIEL GUILBERT.

[Abstracted from Comptes Rendus, Paris Acad., June 7, 1920, pp. 1398-1399.]

The following rules for the forecasting of weather have been deduced from the observation of cirrus clouds:

1. Cirri come from the center of the depression: Cirri from the north indicate a LOW in the north; cirri from the south indicate a LOW in the south.

2. The speed of the cirrus is directly related to the strength of the cyclone; rapid movement indicates a deep depression, slow movement indicates a shallow depression.

3. In the same manner that cirri can be used to forecast a depression, even before the depression has appeared, the known location of a depression can be utilized for forecasting cloudiness.

The following facts are shown by observation:

1. That the initial direction of the movement of the depression is the same as that of the cirrus, but that the path of the depression is independent of the direction of cirrus. They may coincide, but this is only accidental. The same is true of the speed, i. e., rapidly moving cirrus may precede a slowly moving depression or vice versa.

2. That the cirri form an integral part of the march of cloudiness, which have been designated by the author since 1886 as the *succession nuageuse*, and that this succession of clouds is independent of the depression.

3. That the forecasting of weather by cirrus must be subordinated to the survey of the barometric situation which can readily render the arrival of cirrus an unreliable criterion.

The use of cirri in connection with the weather map may thus afford an accurate and reliable method of forecasting. The author has used this method with success for many years, and has presented his views in a work entitled *Nouvelle méthode de prévision du temps*, published in Paris in 1909.—*C. L. M.*

## RELATION OF WEATHER TO FRUITFULNESS IN THE PLUM.

In Paper No. 162, Journal Series, Minnesota Agricultural Experiment Station, Mr. M. J. Dorsey discusses the effect of weather on the setting of plum fruit. The erratic productive nature of this fruit, exemplified in over-production one year and perhaps complete failure in another, sometimes regardless of the number of fruit-buds appearing, led to an attempt to determine the cause of this wide difference from year to year in the fertilization process.

The study is based on meteorological and fruiting data collected during a period of 7 years. It was found that no fruit set from wind-carried pollen when insects were excluded. It was concluded, therefore, that wind may be regarded as having a more indirect than direct bearing on the setting of fruit, in that its influence upon bee flight may be serious at certain times, bees being the chief pollinizer of the plum.

Temperature is considered of primary importance from three standpoints: Its effect upon pollen or pistil; its influence upon pollen tube growth; and its interference with bee flight. The time required for germination was considerably increased as a result of low temperature. The action of low temperature in retarding pollen tube growth is considered as one of the principal causes of the failure of fruit to set, as it was shown that plum pollen does not germinate at temperatures below 40°, and even at 51° there is slow pollen tube growth. Sunshine showed no direct bearing on the fertilization.

Rainfall was found to have a more direct effect than any of the other weather elements. Anthers close rapidly when coming into contact with water and remain closed as long as they are wet, preventing pollination under such conditions, and, furthermore, rain prevents insect flight.

In summarizing it is pointed out that unfavorable weather at blooming time may completely prevent the setting of fruit, even though there be a full bloom, and that rain and low temperatures are the most important factors, although strong wind when prolonged is important. The greatest damage from low temperature is in the retarding of pollen tube growth. Cloudiness has no injurious effect in the setting of fruit, but rain, by causing the anthers to close or preventing them from opening, prevents pollen dissemination. In one season, rain during bloom may be the limiting factor, while in another it may be low temperatures during the period of tube growth.—*Nat'l Weather and Crop Bull.*

## MONTANA RAINFALL.

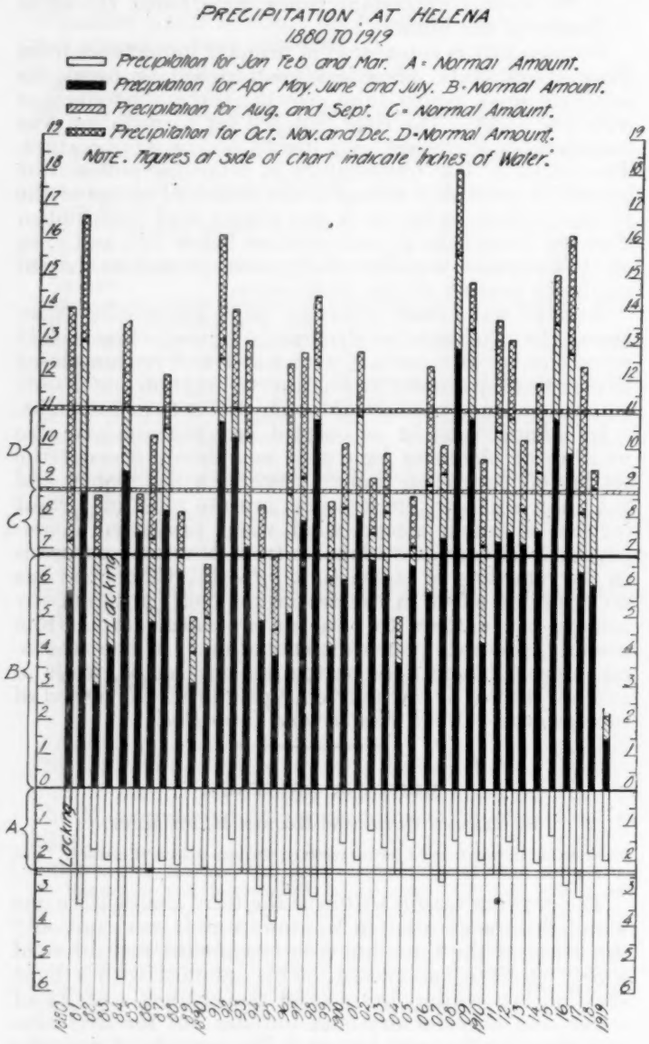
By EDMUND BURKE and REUBEN M. PINCKNEY.

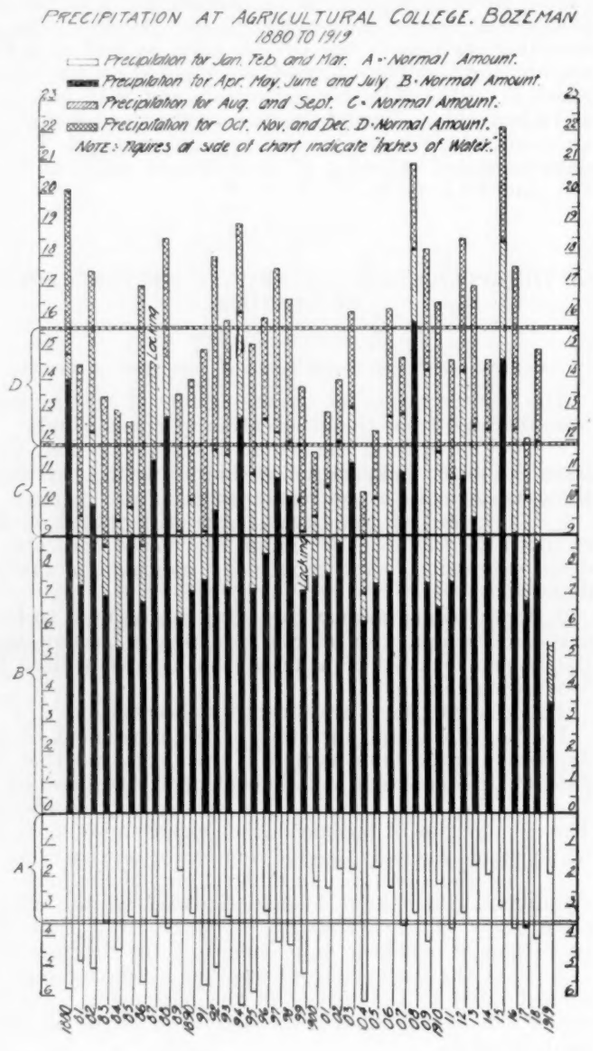
[Excerpts and abstract from "A further report on Montana climate," Circular 87, Univ. of Montana Agricultural Experiment Station, Bozeman, Mont., Sept., 1919, 15 p.]

The growing season 1919 was the third consecutive one with light precipitation in Montana, and it was "not only the driest of the three but also the hottest and driest of which we have any record. This, coupled with a light snowfall last winter, has caused the greatest scarcity of water, not only for dry-land farming but for irrigation and city supplies, ever known. The scarcity of moisture has probably never been felt more keenly than this year, and it is therefore but natural that the people are unusually interested in weather conditions. It is the purpose of this circular to present sufficient data to give the public a comprehensive idea of precipitation in the past, since it is safe to assume that like conditions will occur in the future. The data given are taken from stations with fairly complete records and so located that the State as a whole is well represented."

In order to answer the frequent question, "How much moisture falls in Montana"? the authors selected 30 stations representing the entire State and averaged the records. For convenience the State was divided into

three natural rainfall sections, which they designated the Eastern Mountain District, the Western Mountain District, and the Plains District. The details of the observations are shown in tables: Normal rainfall for the growing season and for the year; Rainfall in the wettest year (1908) and the driest year (1904); Rainfall for the years 1917, 1918, and 1919; Monthly mean humidity for the growing season at Bozeman (the Agricultural Experiment Station); and Monthly mean temperatures for the growing season.


PRECIPITATION AT HELENA
1880 TO 1919
Precipitation for Jan. Feb. and Mar. A = Normal Amount.
Precipitation for Apr. May, June and July. B = Normal Amount.
Precipitation for Aug. and Sept. C = Normal Amount.
Precipitation for Oct. Nov. and Dec. D = Normal Amount.
NOTE. Figures at side of chart indicate "Inches of Water."
A
B
C
D
Locking


PRECIPITATION AT AGRICULTURAL COLLEGE, BOZEMAN
1880 TO 1919
Precipitation for Jan. Feb. and Mar. A = Normal Amount.
Precipitation for Apr. May, June and July. B = Normal Amount.
Precipitation for Aug. and Sept. C = Normal Amount.
Precipitation for Oct. Nov. and Dec. D = Normal Amount.
NOTE: Figures at side of chart indicate "Inches of Water."
A
B
C
D
Locking

To quote from the authors: "The mountain district west of the main range shows an annual rainfall of 15.75 inches, with geographic extremes ranging from 11.65 inches to 22.13 inches. The average rainfall for the growing season of April, May, June, and July is 6.23 inches, or but 40 per cent of the annual. In the northwestern corner of the State the seasonal rainfall is even a smaller proportion. Only 26 per cent of the rain of the year comes in May and June. This district must make a special effort to conserve the fall and winter precipitation.

In the Mountain District east of the main range the average yearly rainfall is 16.22 inches, varying from 11.09 inches at one place to 23.53 inches at another. The rainfall for April, May, June, and July is 53 per cent of the annual and that for May and June is 35 per cent of the annual.

"* * *, The plains area of the State is drier than either of the mountain areas. The average yearly precipitation is 13.63 inches, with a geographic range from 12.06 inches to 15.51 inches. The rainfall for the growing season is about 55 per cent of the annual and that for May and June is 37 per cent of the annual.

"Contrasting the districts east of the continental divide, it is noted that while the plains district has over 2½ inches less annual rainfall it has only $1\frac{2}{10}$ inches less during the growing season and about seven-tenths of an inch less in May and June. * * *."

"In addition to the tables, we are presenting four charts so constructed that the rainfall for the growing months is easily distinguished from the preceding and following months of each year. The points selected are Helena, Havre, Miles City, and the Agricultural College [at Bozeman], the four stations in the State that have the longest records, three of them dating back to 1880. These charts present the most reliable information obtain-

able and bring out the seasonal and annual variation in a very striking manner.

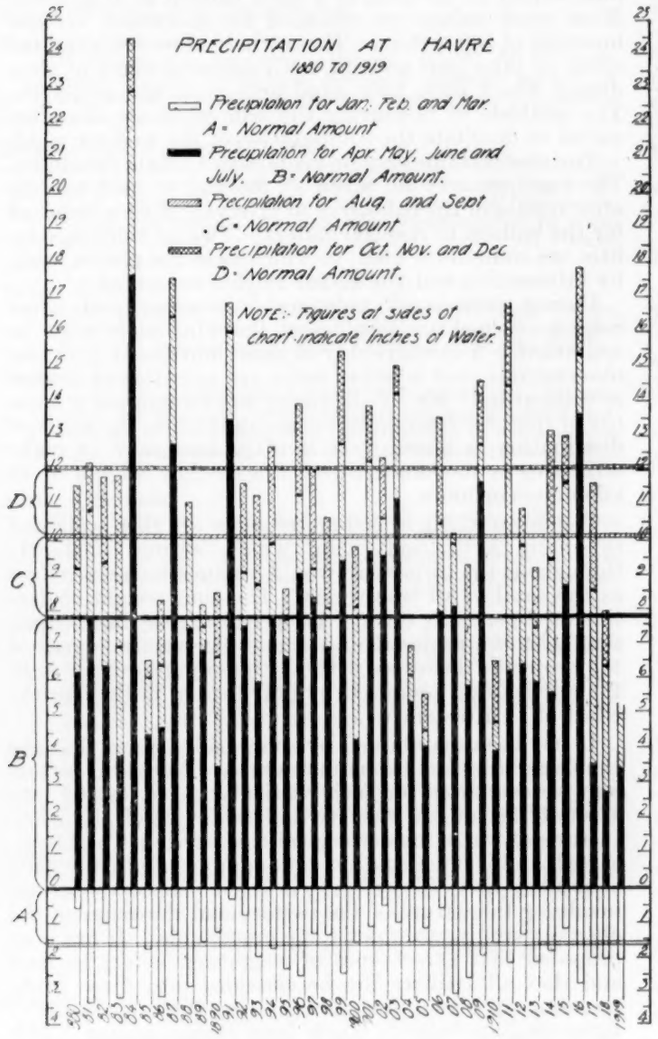
"In studying these charts it should be remembered that the rain which falls just when the crop needs it is subjected for only a limited time to the forces that tend to remove it, so this seasonal rainfall has a much greater value, so far as producing crops is concerned, than that which falls before the crop is ready to use it. * * *

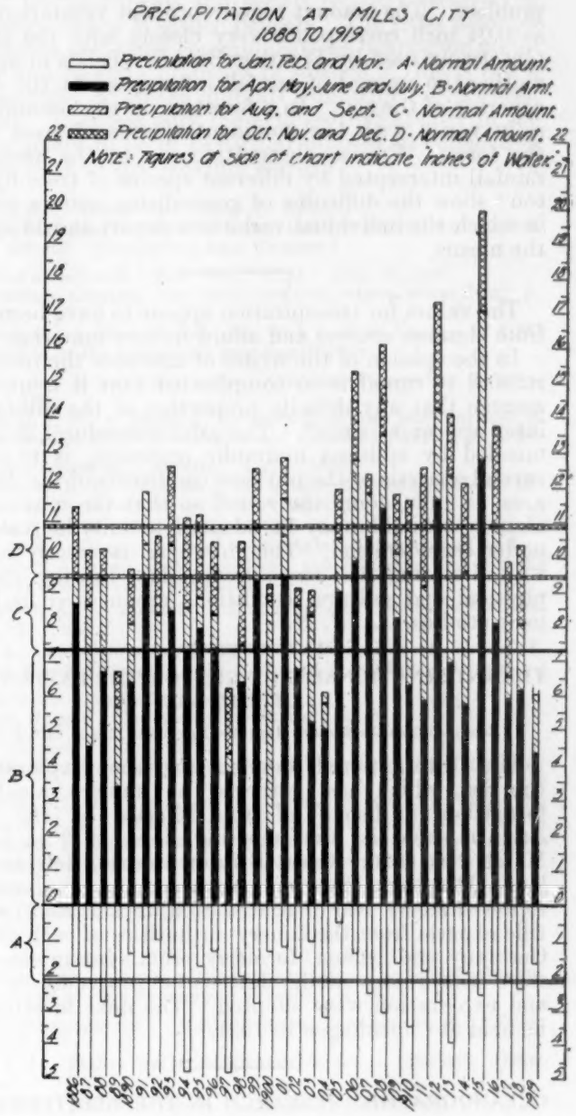
"* * * The average rainfall for all points which have long records proves to be very constant" [i. e., shows no secular change].

"But not all the water that falls on the land is used by the crop planted. The various sources of loss of moisture are (1) water that runs off; (2) water that sinks too deep for crops to reach it; (3) water that evaporates from the soil; (4) water used by growing weeds."

The four months for 1919 had higher mean temperatures than any of the similar dry years—1904 (driest), 1917, 1918—thus reducing the value of what moisture the soil had, so far as influenced by temperature, and reducing the available supply below that of the other years.

In preparing this bulletin the writers had the able cooperation of Mr. William T. Lathrop, meteorologist, Montana section, United States Weather Bureau, in assembling the data from official sources.—*H. L.*


PRECIPITATION AT HAVRE
1880 TO 1919
Precipitation for Jan. Feb. and Mar. A - Normal Amount
Precipitation for Apr. May, June and July. B - Normal Amount.
Precipitation for Aug. and Sept. C - Normal Amount
Precipitation for Oct. Nov. and Dec. D - Normal Amount.
NOTE:- Figures at sides of chart indicate Inches of Water.
A
B
C
D


PRECIPITATION AT MILES CITY
1886 TO 1919
Precipitation for Jan. Feb. and Mar. A - Normal Amount.
Precipitation for Apr. May, June and July. B - Normal Amt.
Precipitation for Aug. and Sept. C - Normal Amount.
Precipitation for Oct. Nov. and Dec. D - Normal Amount.
NOTE:- Figures at side of chart indicate Inches of Water.
A
B
C
D

## RAINFALL AND LAND DRAINAGE.[1]

Dr. Brysson Cunningham reviews in Nature of March 11, 1920, the three papers listed in the footnote below. These papers, as indicated by their respective titles, treat of the disposal of rainfall from several points of view.

In the first paper the proportion of runoff to rainfall is discussed a problem that has also been studied extensively in this country. Col. Craster finds that 0.065 inch of water is required to wet a crop of rough grass about 5 inches in height, the aftermath of a hay field,

[1] Estimating river flow from rain all records, by Lieut. Col. J. E. E. Craster. *Engineering*, Jan. 2, 1920. Land drainage from the engineering point of view, by C. H. J. Clayton. Land drainage from the administrative point of view, by E. M. Konstam. (The last two are papers read before the Surveyors' Institution on Jan. 12, 1920.)

up to the point at which it commences to drip onto the soil. It is therefore assumed that not less than 0.04 inch, or 1 mm., of water is required to wet vegetation and the surface of plowed land. This amount is, of course, lost by direct evaporation after the fall of every rain. It is this part of the summary by Dr. Cunningham that is of particular interest to American students of the problem. The amount required to wet vegetation given as 0.04 inch corresponds very closely with the amount tentatively used by Weather Bureau officials in approximating the amount of rainfall intercepted by the vegetal covering of the soil. In a forest cover the amount naturally varies with the dominant species of trees within the forest. Precise observations as to the amount of rainfall intercepted by different species of trees by Horton [2] show the difficulty of generalizing upon a problem in which the individual variations depart so widely from the means.

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The values for transpiration appear to have been taken from German sources and afford no new material.

In the opinion of the writer of this note the relation of rainfall to runoff is so complicated that it is unsafe to assume that any definite proportion of the rainfall will later appear as runoff. The safer procedure, as recommended by eminent hydraulic engineers, is to make a careful analysis of the physical conditions of the drainage area as influencing the runoff so that the mean results already available may be adapted to suit the watershed under consideration. This, however, is merely another way of stating that more precise data bearing upon the physical and cultural conditions are needed in hydrologic studies.—*A. J. H.*

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## THE INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA.

[Reprinted from the *Scientific American*, New York, June 19, 1920, p. 669.]

The International Council for the Exploration of the Sea, which has gathered so much valuable information in behalf of the fisheries of the North Atlantic, held its first meeting since 1913 in London March 2–6, 1920. Great Britain, France, Belgium, Holland, Denmark, Sweden, Norway, and Finland were represented by two delegates each, in addition to scientific experts from the fishery authorities of each country. Germany and Russia, formerly prominent in this work, were not represented. Extensive programs of study and exploration were adopted. The next meeting is to be held at Copenhagen in 1921.

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## OCEANOGRAPHIC RESEARCH IN THE MEDITERRANEAN.

[Reprinted from *Scientific American*, New York, June 26, 1920, p. 697.]

An international conference which met recently in London took steps to organize cooperative researches in the Mediterranean, in which the various countries bordering that sea will take part. A permanent central office of fisheries is to be opened at Monaco, and regular campaigns of fishery investigations will be made every spring and autumn. Four ships will be at the disposal of the office. Cooperative hydrographic surveys will also be carried out. Results of these activities will be published in a bulletin in French, Italian, Spanish, and English.

[2] Horton, Robert E.: Rainfall interception. MONTHLY WEATHER REVIEW, September, 1919, 47: 603–623.

## THE BALLISTIC WIND.

By Lieut. I. R. TANNEHILL.

[Author's abstract.]

[From *Journal of the United States Artillery*, June, 1920, p. 553–576.]

The true wind movement aloft is determined from the observation of the drift of a pilot balloon as it ascends. Mean wind values are obtained for successive vertical intervals of 500 meters. These wind values are weighted so as to take into account the relative amount of time during which each zone wind acts upon the projectile. The methods of measuring the true wind are therefore varied to facilitate the computation of the ballistic wind.

The observations may be made with a single theodolite. The readings may be taken at the end of each minute after release of the balloon or at intervals of time required for the balloon to rise 500 meters. Two or more theodolites are sometimes used, in which case the plot is made by intersection and the actual heights computed.

During periods of unfavorable weather and when heights reached are insufficient the wind aloft must be estimated. A careful study of cloud movement, previous observations, and weather maps are essential to success in estimating. Mr. W. R. Gregg has formulated a number of rules for forecasting winds aloft when the pressure distribution is known. It is often necessary to make estimates as modern artillery fire reaches heights of 10 kilometers or more.

The mean winds in 500-meter zones are then weighted to obtain a fictitious wind which, acting constantly throughout the trajectory, would produce the same effect as the total of all true winds. The time weighting factors used generally during the recent war are based upon the flight of a projectile in vacuo. The vertical speed of the projectile decreases with altitude in accordance with the acceleration produced by gravitation, neglecting the effect of air resistance.

It has been maintained by some ballisticians that the time weighting factors are inaccurate. Weighting factors may be computed for each particular piece, taking into account the muzzle velocity and the angle of elevation. In time of war a meteorological message must be broadcasted, and it must contain data appropriate to any class of artillery fire. Therefore it is urged that computations involving the nature of the battery and the range of the objective are too complex to be practicable. It has been proposed that three types of weighting factors be used and that all artillery fire be classified into three corresponding divisions, thus necessitating the preparation of three separate ballistic winds from each sounding. This proposition is under investigation.

The battery commander receives the meteorological message and determines the effect of the wind upon the range and direction of his firing. Prior to the introduction of pilot balloon methods surface wind values were used, and the charts employed in finding corrections were prepared with the assumption that the wind at 1,000 feet is approximately twice the ground wind. Because of the extreme ranges and the great heights to which modern artillery fire reaches, the use of the ballistic wind is essential to the attainment of effective fire. Range tables are being prepared in which are tabulated the variations in range and direction due to the wind aloft as actually measured by means of pilot balloons. Until such tables are available caution is advised in avoiding the natural error which arises from applying a ballistic wind value to a range chart intended for surface wind use only.

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## SPECIAL OBSERVATIONS.

### SOLAR AND SKY RADIATION MEASUREMENTS DURING MAY, 1920.

By HERBERT H. KIMBALL, Professor of Meteorology.

[Dated: Solar Radiation Investigations Section, Washington, July 1, 1920.]

For a description of instruments and exposures, and an account of the method of obtaining and reducing the measurements, the reader is referred to this REVIEW for April, 1920, **48**: 225.

The monthly means and departures from normal in Table 1 indicate that solar radiation intensities were generally above normal except at Lincoln, Nebr. At this station the average cloudiness for the month was 76 per cent, and on only two days did the cloudiness average less than 50 per cent.

As a result of this unusually cloudy condition, Table 2 shows a deficiency in the total radiation received on a horizontal surface at Lincoln during the four weeks April 30 to May 27, inclusive. At Madison all the weeks except the one beginning May 7 show an excess of radiation, while at Washington weeks with excess and deficiency of radiation alternate.

Skylight polarization measurements obtained at Washington on six different days give a maximum of 64 per cent and a mean for the month of 57 per cent. Measurements obtained at Madison on nine days give a maximum of 67 per cent and a mean of 56 per cent. These are above the average values for May at Washington, and slightly above at Madison.

TABLE 1.—*Solar radiation intensities during May, 1920.*

[Gram-calories per minute per square centimeter of normal surface.]

WASHINGTON, D. C.

| Date. | Suns zenith distance. | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8 a.m. | 78.7 | 75.7 | 70.7 | 60.0 | 0.0 | 60.0 | 70.7 | 75.7 | 78.7 | Noon. |
| | 75th meridian time. | Air mass. | | | | | | | | | Local mean solar time. |
| | | A. m. | | | | | P. m. | | | | |
| | e. | 5.0 | 4.0 | 3.0 | 2.0 | 1.0* | 2.0 | 3.0 | 4.0 | 5.0 | e. |
| | *mm.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *mm.* |
| May 1 | 4.95 | | | | | 1.44 | | | | | 3.81 |
| 3 | 4.57 | | | | 1.22 | | | | | | 4.17 |
| 5 | 6.50 | 0.61 | 0.72 | 0.88 | 0.98 | | 1.02 | 0.81 | 0.69 | | 4.57 |
| 6 | 4.95 | 0.68 | 0.83 | 0.95 | 1.17 | 1.39 | | | | | 3.99 |
| 10 | 7.57 | | | | 0.84 | | | | | | 5.36 |
| 15 | 5.16 | | 0.73 | 0.93 | 1.13 | 1.37 | | | | | 3.99 |
| 17 | 6.50 | 0.81 | 0.84 | 0.94 | 1.13 | 1.28 | | | | | 4.37 |
| 22 | 9.14 | 0.73 | 0.84 | 0.96 | 1.14 | 1.34 | | | | | 6.76 |
| 27 | 10.21 | 0.52 | 0.59 | 0.74 | 0.92 | 1.16 | | | | | 10.21 |
| 28 | 11.38 | | | | | | 1.10 | | | | 12.24 |
| 29 | 8.81 | | | | | 1.25 | | | | | 6.76 |
| Means | | 0.67 | 0.76 | 0.90 | 1.07 | 1.32 | (1.06) | (0.81) | (0.69) | | |
| Departures | | +0.06 | +0.04 | +0.09 | +0.09 | +0.03 | +0.07 | +0.02 | −0.01 | | |

* Extrapolated.

TABLE 1.—*Solar radiation intensities during May, 1920*—Continued.

**MADISON, WIS.**

| Date. | Suns zenith distance. 8 a.m. | 78.7 | 75.7 | 70.7 | 60.0 | 0.0 | 60.0 | 70.7 | 75.7 | 78.7 | Noon. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 75th meridian time. | Air mass. A. m. | | | | | P. m. | | | | Local mean solar time. |
| | e. | 5.0 | 4.0 | 3.0 | 2.0 | 1.0* | 2.0 | 3.0 | 4.0 | 5.0 | e. |
| | *mm.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* | *mm.* |
| May 8 | 7.04 | | | | 1.02 | | | | | | 5.79 |
| 14 | 3.81 | | | | | 1.29 | 1.04 | 0.83 | | | 4.17 |
| 19 | 8.48 | | | | | 1.34 | | | | | 6.27 |
| 20 | 5.16 | | | | | 1.38 | | | | | 8.18 |
| 21 | 6.27 | | | | | 1.38 | | | | | 7.04 |
| 24 | 7.87 | | | 0.93 | | 1.44 | 1.21 | | | | 8.48 |
| 25 | 9.83 | | | | | 1.44 | 1.01 | | | | 7.57 |
| 29 | 6.27 | | | 1.05 | 1.18 | 1.35 | | | | | 5.79 |
| Means | | | | (0.99) | (1.10) | 1.37 | 1.09 | (0.83) | | | |
| Departures | | | | +0.08 | ±0.00 | +0.03 | +0.05 | −0.08 | | | |

**LINCOLN, NEBR.**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May 8 | 6.76 | | | | 0.79 | | | | | | 6.02 |
| 21 | 7.87 | | | | 1.23 | | | | | | 8.81 |
| Means | | | | | (1.01) | | | | | | |
| Departure | | | | | −0.13 | | | | | | |

**SANTA FE, N. MEX.**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May 1 | 2.74 | | 1.05 | 1.17 | | | | | | | 2.49 |
| 4 | 1.88 | | | 1.27 | 1.42 | 1.60 | | | | | 3.15 |
| 6 | 1.78 | 1.06 | 1.21 | 1.33 | 1.44 | 1.61 | 1.42 | 1.27 | 1.16 | | 2.49 |
| 7 | 2.36 | 0.91 | 1.01 | 1.11 | 1.28 | | | | | | 6.50 |
| 18 | 3.81 | | | 1.23 | | | | | | | 4.17 |
| 20 | 3.81 | | 1.05 | 1.20 | 1.30 | 1.50 | | | | | 3.30 |
| 24 | 7.29 | | 0.98 | 1.12 | | | | | | | 5.36 |
| 28 | 6.50 | | | 1.08 | | | 1.34 | | | | 4.75 |
| 29 | 6.02 | | 1.06 | 1.17 | 1.31 | | | | | | 4.95 |
| Means | | (0.98) | 1.06 | 1.19 | 1.35 | 1.57 | (1.38) | (1.27) | (1.16) | | |
| Departures | | −0.03 | ±0.00 | +0.02 | +0.06 | +0.05 | +0.14 | −0.07 | | | |

* Extrapolated.

TABLE 2.

| Week beginning— | Average daily radiation. Washington. | Madison. | Lincoln. | Average daily departure for the week. Washington. | Madison. | Lincoln. | Excess or deficiency since first of year. Washington. | Madison. | Lincoln. |
|---|---|---|---|---|---|---|---|---|---|
| | *cal.* | *cal.* | *cal.* | *cal* | *cal.* | *cal.* | *cal.* | *cal.* | *cal.* |
| Apr. 30 | 605 | 516 | 404 | 104 | 64 | − 47 | 1,247 | −1,028 | −2,665 |
| May 7 | 394 | 423 | 406 | − 92 | − 41 | − 71 | 601 | −1,318 | −3,163 |
| May 14 | 513 | 505 | 367 | 23 | 31 | −135 | 759 | −1,104 | −4,106 |
| May 21 | 395 | 584 | 502 | − 99 | 107 | − 10 | 69 | − 357 | −4,179 |

## MEASUREMENTS OF THE SOLAR CONSTANT OF RADIATION AT CALAMA, CHILE.

By C. G. ABBOT, Assistant Secretary.

(Smithsonian Institution, Washington, June 30, 1920.)

In continuation of preceding publications, I give in the following table the results obtained at Calama, Chile, in April, 1920, for the solar constant of radiation. The reader is referred to this REVIEW for February, August, and September, 1919, for statements of the arrangement and meaning of the table.

| Date. | Solar constant. | Method. Grade. | Transmission coefficient at 0.5 micron. | Humidity. ρ/ρSC. | V. P. | Rel. hum. | Remarks. |
|---|---|---|---|---|---|---|---|
| 1920. | | | | | | | |
| A. M. | *cal.* | | | | *cm.* | *Per cent.* | |
| Apr. 1 | 1.937 | $E_0$..... E− | 0.842 | 0.358 | 0.39 | 35 | |
| | 1.938 | $M_3$ | | | | | |
| | 1.952 | $M_2$ | | | | | |
| | 1.944 | $M_{1.5}$ | | | | | |
| | 1.944 | W. M. | | | | | |
| 2 | 1.956 | $M_3$..... S | .844 | .367 | .43 | 45 | |
| | 1.962 | $M_2$ | | | | | |
| | 1.960 | W. M. | | | | | |
| 3 | 1.951 | $M_{1.5}$..... S− | .851 | .540 | .36 | 25 | Cirri in east and west. |
| | 1.961 | $M_{1.87}$ | | | | | |
| | 1.956 | W. M. | | | | | |
| 4 | 1.939 | $M_3$..... S− | .855 | .468 | .34 | 30 | Distant cirri in east and southwest. |
| | 1.974 | $M_2$ | | | | | |
| | 1.962 | W. M. | | | | | |
| 5 | 1.964 | $M_3$..... S− | .853 | .597 | .32 | 37 | |
| | 1.951 | $M_{1.5}$ | | | | | |
| | 1.960 | W. M. | | | | | |
| 6 | 1.942 | $E_0$..... G+ | .838 | .508 | .23 | 24 | |
| | 1.915 | $M_3$ | | | | | |
| | 1.918 | $M_{1.5}$ | | | | | |
| | 1.925 | W. M. | | | | | |
| 7 | 1.902 | $M_3$..... S | .863 | .520 | .27 | 21 | |
| | 1.921 | $M_2$ | | | | | |
| | 1.922 | $M_{1.5}$ | | | | | |
| | 1.916 | W. M. | | | | | |
| 8 | 1.928 | $M_3$..... S | .860 | .518 | .27 | 22 | Cirri low in northeast. |
| | 1.924 | $M_2$ | | | | | |
| | 1.933 | $M_{1.5}$ | | | | | |
| | 1.927 | W. M. | | | | | |
| 9 | 1.965 | $E_0$..... E | .848 | .463 | .32 | 30 | |
| | 1.955 | $M_3$ | | | | | |
| | 1.961 | $M_2$ | | | | | |
| | 1.956 | $M_{1.5}$ | | | | | |
| | 1.960 | W. M. | | | | | |
| 10 | 1.960 | $E_0$..... E− | .866 | .515 | .36 | 32 | |
| | 1.964 | $M_3$ | | | | | |
| | 1.960 | $M_2$ | | | | | |
| | 1.963 | $M_{1.5}$ | | | | | |
| | 1.961 | W. M. | | | | | |
| 11 | 1.956 | $M_{1.77}$... S | .868 | .678 | .27 | 17 | Thin cirri scattered over sky, especially in east. |
| | 1.961 | $M_{1.5}$ | | | | | |
| | 1.958 | W. M. | | | | | |
| 12 | 1.950 | $M_{1.56}$... S− | .855 | .568 | .36 | 23 | Cirri scattered about sky, preventing earlier observations. |
| | 1.959 | $M_{1.5}$ | | | | | |
| | 1.955 | W. M. | | | | | |
| 13 | 1.967 | $E_0$..... VG− | .854 | .488 | .31 | 30 | Cirro-cumuli forming low in east. Cirri also appearing in northwest. Chuqui smoke in all observations. |
| | 1.977 | $M_3$ | | | | | |
| | 1.949 | $M_2$ | | | | | |
| | 1.941 | $M_{1.5}$ | | | | | |
| | 1.954 | W. M. | | | | | |
| 14 | 1.954 | $E_0$..... E | .864 | .566 | .26 | 26 | Wind carried much dust at times. |
| | 1.961 | $M_3$ | | | | | |
| | 1.958 | $M_2$ | | | | | |
| | 1.952 | $M_{1.5}$ | | | | | |
| | 1.957 | W. M. | | | | | |
| 15 | 1.930 | $M_3$..... S− | .861 | .541 | .25 | 22 | Chuqui smoke interfered with $M_3$ observations. |
| | 1.944 | $M_2$ | | | | | |
| | 1.959 | $M_{1.5}$ | | | | | |
| | 1.944 | W. M. | | | | | |
| 16 | 1.910 | $M_3$..... S− | .859 | .528 | .28 | 24 | Some cirri in north. Chuqui smoke interfered with all observations. |
| | 1.963 | $M_2$ | | | | | |
| | 1.935 | W. M. | | | | | |
| 17 | 1.939 | $M_3$..... S− | .832 | .466 | .29 | 33 | Cirri in west extending east. Cirri approaching sun at $M_2$ preventing further observations. |
| | 1.950 | $M_2$ | | | | | |
| | 1.946 | W. M. | | | | | |
| 18 | 1.952 | $M_3$..... S | .852 | .433 | .41 | 39 | Chuqui smoke interfered. |
| | 1.953 | $M_2$ | | | | | |
| | 1.953 | W. M. | | | | | |
| 19 | 1.950 | $E_0$..... E | .845 | .406 | .38 | 33 | |
| | 1.956 | $M_3$ | | | | | |
| | 1.944 | $M_2$ | | | | | |
| | 1.944 | $M_{1.5}$ | | | | | |
| | 1.948 | W. M. | | | | | |

| Date. | Solar constant. | Method. | Grade. | Transmission coefficient at 0.5 micron. | Humidity. | | | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | | | | $\rho/\rho$SC. | V. P. | Rel. hum. | |
| 1920. | | | | | | | | |
| A. M. | *cal.* | | | | | *cm.* | *Per cent.* | |
| Apr. 20 | 1.957 | $M_3$..... | S | 0.853 | 0.438 | 0.36 | 27 | |
| | 1.960 | $M_2$..... | | | | | | |
| | 1.955 | $M_{1.5}$..... | | | | | | |
| | 1.958 | W. M.. | | | | | | |
| 21 | 1.929 | $M_3$..... | S— | .847 | .408 | .43 | 39 | Cirri around most of horizon. Probably smoke from Chuqui affected $M_3$ and $M_{1.5}$ observations. |
| | 1.943 | $M_2$..... | | | | | | |
| | 1.934 | $M_{1.5}$..... | | | | | | |
| | 1.937 | W. M.. | | | | | | |
| 22 | 1.935 | $E_0$..... | VG— | .856 | .492 | .38 | 39 | Chuqui smoke affected earlier observations. |
| | 1.965 | $M_3$..... | | | | | | |
| | 1.935 | $M_2$..... | | | | | | |
| | 1.964 | $M_{1.5}$..... | | | | | | |
| | 1.949 | W. M.. | | | | | | |
| 23 | 1.966 | $M_3$..... | S— | .856 | .456 | .29 | 26 | Cirri in north. Chuqui smoke interfered. Also dust clouds in $M_3$. |
| | 1.950 | $M_2$..... | | | | | | |
| | 1.934 | $M_{1.5}$..... | | | | | | |
| | 1.950 | W. M.. | | | | | | |
| 24 | 1.948 | $M_{1.33}$... | S— | .860 | .635 | .34 | 20 | Cirri scattered about sky, preventing earlier observations. Chuqui smoke and dust from gusty east wind bad. |
| 25 | 1.956 | $M_3$..... | S | 0.849 | 0.406 | 0.29 | 25 | |
| | 1.945 | $M_2$..... | | | | | | |
| | 1.949 | W. M.. | | | | | | |
| 26 | 1.953 | $E_0$..... | VG+ | .858 | .446 | .30 | 26 | |
| | 1.970 | $M_3$..... | | | | | | |
| | 1.957 | $M_2$..... | | | | | | |
| | 1.957 | $M_{1.5}$..... | | | | | | |
| | 1.960 | W. M.. | | | | | | |
| 27 | 1.954 | $M_3$..... | S— | .826 | .446 | .29 | 25 | Smoke from Chuqui. Wind carried dust during $M_3$. |
| | 1.948 | $M_2$..... | | | | | | |
| | 1.948 | $M_{1.5}$..... | | | | | | |
| | 1.949 | W. M.. | | | | | | |
| 28 | 1.943 | $M_{1.33}$... | S— | .850 | .518 | .39 | 16 | Thin cirri in east. Cumuli forming over mountains. Probably Chuqui smoke early. |
| 29 | 1.975 | $M_2$..... | S | .859 | .525 | .33 | 18 | Cirri in northeast and west. Chuqui smoke early in morning. |
| | 1.969 | $M_{1.5}$..... | | | | | | |
| | 1.972 | W. M.. | | | | | | |
| 30 | 1.980 | $M_{1.33}$... | S— | .852 | .634 | .35 | 19 | Distant cirri in west. Dust interfering with observations. Probably some smoke. |
| | 1.959 | $M_{1.27}$... | | | | | | |
| | 1.959 | W. M.. | | | | | | |

# WEATHER OF THE MONTH.

## WEATHER OF NORTH AMERICA AND ADJACENT OCEANS.

### GENERAL PRESSURE CONDITIONS.

By H. C. FRANKENFIELD, Supervising Forcaster.

(Dated June 15, 1920.)

*North Pacific Ocean.*—At Midway Island pressure was below normal throughout the month, except on May 29, with a great depression (29.56 inches), on May 4, and another of somewhat less intensity (29.70 inches), on May 10. Pressure was also low at Honolulu during the month, except from May 12 to 15, inclusive, when it was about normal.

*Alaska.*—Over northern Alaska and the Aleutian Islands reverse conditions prevailed, except on a few days, with principal crests of high pressure during the first week of the month and about May 25. Over central Alaska moderately high pressure also prevailed, except between May 15 and 25, when it was low, while over southern Alaska changes were not very decided, with a tendency toward slightly below normal conditions, except between May 9 and 15 and at the close of the month.

*United States.*—There were no great HIGHS or LOWS during the month, and the general pressure distribution may be roughly divided into two periods, one of moderately high pressure, a part of the Alaska and Aleutian high that moved southeastward across the Canadian Northwest and the western portion of the United States during the first half of the month, gradually transferring itself over eastern Canada and the eastern portion of the United States during the first 10 days of the second half of the month, and another of rapidly alternating high and low pressure within very moderate limits that followed the high pressure over the western portion of the country during the second half of the month, reaching the Atlantic coast during the closing days.

*North Atlantic Ocean.*—Stations of observation at Bermuda and Horta. Moderately high pressure prevailed during the first three weeks of the month, and low pressure thereafter, with a marked depression on May 24 and 25.

### NORTH PACIFIC OCEAN.

By F. G. TINGLEY.

Atmospheric conditions over the North Pacific Ocean showed greater activity during May than in April. Several well-developed depressions occurred during the month of which perhaps the most important was that which prevailed from the 11th to the 15th over the region south and southeast of the Aleutian Islands. The Japanese S. S. *Kinkasan Maru*, Capt. Gillespie, from Meike for San Francisco, encountered this storm, and on May 12, when in latitude 45° 20′ N., 158° 42′ W., reported as follows:

> Strong to whole gale, very high sea. Ship laboring and straining heavily. Glass fell to 28.95 (28.88 inches, corrected) at 6 p. m., which was the lowest.

It is possible that this storm was a redevelopment of one which prevailed from the 4th to the 7th west and northwest of Midway Islands and which caused at times winds reaching the force of a strong gale.

In Asiatic waters pressure was moderately low during the month, with a succession of depressions moving northeastward over the Japanese islands. Of these, the principal one appears to have been that of the 24th to 26th. On the 25th a barometer reading of 28.91 inches was reported by a ship immediately to the eastward of the Tsugura Strait.

Pressure was much above the normal over Bering Sea during the first and third decades and moderately so during the second decade. From May 1 to 10 the average pressure at Dutch Harbor was 30.36 inches—approximately one-half inch above the normal. It is

probable that the presence of this high pressure was responsible for the unusual amount of fog reported by vessels on the northern steamer route, as well as for the dense cloudiness frequently experienced.

## NORTH AMERICA.

By H. C. FRANKENFIELD, Supervising Forecaster.

As indicated in the general discussion above, pressure distribution during the month of May was not of decisive character. On the whole, pressure somewhat above normal prevailed, with resulting low temperatures over the greater portion of the country, only the Southwest, a small section of the near Northwest, and the southern districts west of the Rocky Mountains reporting a slight excess. There were no severe storms, but precipitation was in excess over the Gulf and Plains States and the upper Mississippi Valley. Elsewhere it was deficient.

## NORTH ATLANTIC OCEAN.

By F. A. YOUNG.

The average pressure for the month was considerably above the normal at land stations on the American and northern European coasts, as well as the Azores, while it was below in the West Indies and Gulf of Mexico.

According to reports received the number of days on which gales occurred over the steamer lanes was not far from the normal, although nearly all of the severe weather was confined to two periods in the first and second decades, respectively, while during the remainder of the month comparatively moderate conditions prevailed.

Fog was apparently somewhat less prevalent than usual over the greater part of the ocean, except in the vicinity of the British Isles, where it was reported on from six to seven days, which is somewhat above the normal.

Charts IX to XII, covering the period from May 2 to 5, inclusive, show a disturbance over the steamer lanes that was especially severe on May 4 and 5.

The storm log from the British S. S. *Chipawa* is as follows:

Gale began on the 2d. Lowest barometer reading, 29.49 inches, at 4 a. m. on the 3d; position, 42° 35′ N., 41° 20′ W. End of gale on the 4th. Highest force, 10; shifts of wind near time of lowest barometer SW–W by S.

The observer on the British S. S. *Derwent River* states:

Gale began on the 4th. Lowest barometer, 29.50 inches, at 2 p. m. on the 4th; position, 47° 20′ N., 35° 15′ W. End of gale on the 6th. Highest force of wind, 9; shifts of wind WSW–NW.

From the 6th to the 12th the conditions over the ocean were nearly normal, and only a few scattered reports were received denoting winds of gale force. On the 13th the British S. S. *Cairndhu* was the only vessel reporting gales; her storm log is as follows:

Gale began on the 13th. Lowest barometer reading, 29.10 inches, at noon on the 13th; position, 51° 34′ N., 43° 17′ W. End of gale 4 p. m. on the 14th. Highest force of wind, 10. [No shifts of wind given.]

Charts XIII and XIV for May 17 and 18, inclusive, show the nearly stationary depression central off the British Isles, and the storm area of limited extent over the eastern part of the steamer lanes. The storm log from the British S. S. *Galtymore* is as follows:

Gale began on the 17th. Lowest barometer reading, 29.65 inches, at 10 a. m. on the 17th; position, 49° 48′ N., 25° 18′ W. End of gale on the 18th. Highest force of wind 10; shift of wind near time of lowest barometer W–NW–N. The observer on the American S. S. *Triumph* states:

Gale began on the 17th. Lowest barometer, 29.53 inches, at 3 a. m. on the 18th; position 49° 38′ N., 11° 00′ W. End of gale on the 19th. Highest force of wind 10; shifts of wind WSW–W by S–W.

From the 19th to the 30th the conditions were comparatively featureless, light to moderate winds prevailing over the entire ocean during that period. Fog was reported on the Banks of Newfoundland from the 19th to the 23d, and off the British coast from the 21st to the 29th. On the 31st two vessels between the 35th and 40th parallels and the 40th and 50th meridians experienced moderate gales, while moderate weather prevailed over the rest of the ocean, with fog in the middle and western sections of the steamer lanes.

## NOTES ON WEATHER IN OTHER PARTS OF THE WORLD.

*Great Britain.*—The exceptionally severe and widespread thunderstorms at the end of the month will long be remembered, but for the most part the weather, though wet, was cool, there being no thundery hot weather until the 20th.

* * * During the first 11 days the atmospheric conditions were decidedly chilly, and there was frost * * * at many inland stations. On the 1st, at Eskdalemuir, a shade minimum of 21° F. was recorded, with 13° F. on the ground. Sleet was also reported at some of the southern stations during these early days, but milder conditions gradually prevailed, and after the 11th the thermometer seldom fell below the freezing point. * * *

Soon after the 20th warm weather became general, and conditions for about a week, especially over southern and eastern England, were very fine, sunny, and warm. * * * On the 26th and 27th a long valley of relatively low pressure was stretched across England and the Netherlands, and within this belt violent thunderstorms occurred [especially on the 29th]. * * * At Shrewton, Wilts, 12 mm. [of rain] fell in 10 minutes, and at Nettlebed, Oxon, 44 mm. in 45 minutes. * * * In Lancashire and Lincolnshire * * * there were floods which caused loss of life and serious damage to property. * * * [At Hallington, 4.10 in. fell in two hours, when the gauge overflowed and the exact total fall was lost. The Lud stream, normally 3 ft. wide and 1 ft. deep, was swollen to a width of 52 yards and a depth of 50 ft.] The general rainfall expressed as a percentage of the average was: England and Wales, 117; Scotland, 164; Ireland, 145.

In London (Camden Square) the * * * mean temperature was 57.5° F., or 3.5° F. above the average. The duration of rainfall was 20.5 hours. * * *[1]

*Southern Europe.*—* * * Under the influence [of anticyclonic conditions] high day temperatures were recorded at many stations, 90° F. at Clermont and Biarritz on the 11th and at Perpignan on the 27th and 29th, and 94° F. at Clermont on the 28th. Both Madrid and Lisbon recorded 86° F. on the 8th, and on the 21st Rome reached 91° F., a temperature not exceeded in May since 1834.[1]

[1] *The Meteorological Magazine*, June, 1920, pp. 99 and 104.

*Spain.*—Madrid, May 14.—Terrific hailstorms, accompanied by thunder and lightning, have swept through central Spain, washing away railway tracks, inundating lowlands, and greatly damaging olive and fruit crops. The bull ring at Toledo is reported under water, and in the outskirts of Madrid trolley lines are blocked by huge quantities of sand that were washed down from the hills upon the tracks.—*New York Evening Post, May 15, 1920.*

*Italy.*— * * * Italy continued to suffer from disastrous drought.[1]

*France.*— * * * On the evening of the 25th a heavy storm, with hail and much wind, burst over Paris, unroofing houses, breaking windows, and destroying crops.[1]

*Germany.*—In Germany * * * there were severe thunder storms and considerable floods.[1]

[1] *The Meteorological Magazine*, June, 1920, pp. 99 and 104.

*Canada.*—In Ontario May was the driest month for 27 years, and the grain crops were backward, while the hay crops promised to be a partial failure. Forest fires developed in Ontario, Quebec, and New Brunswick, but fortunately the flames were checked by heavy rains at the beginning of June.[1]

*Egypt.*—Cairo recorded 99° F. on the 27th.[1]

*New South Wales.*—The wheat crop has been disastrously affected by the drought which has existed in all parts of New South Wales. It is estimated that the yield of the present season will be only 4,296,000 bushels, the smallest amount during the past 20 years. There is, in fact, an insufficient amount of wheat even for domestic consumption in Australia.—*Commerce Reports, Washington, D. C., May 26, 1920.*

[1] *The Meteorological Magazine*, June, 1920, pp. 99 and 104.

## DETAILS OF THE WEATHER OF THE MONTH IN THE UNITED STATES.

### CYCLONES AND ANTICYCLONES.

By R. HANSON WEIGHTMAN, Meteorologist.

*Cyclones.*—The number of LOWS was much greater than the average, the month being unusual on account of the great number of secondary developments. The table which follows gives the number of lows by types.

*Lows.*

| | Alberta. | North Pacific. | South Pacific. | Northern Rocky Mountain. | Colorado. | Texas. | East Gulf. | South Atlantic. | Central. | Total. |
|---|---|---|---|---|---|---|---|---|---|---|
| May, 1920 | 5.0 | 0.0 | 0.0 | 2.0 | 7.0 | 1.0 | 2.0 | 2.0 | 0.0 | 19.0 |
| Average number, 1892–1912 | 2.9 | 1.3 | 1.2 | 0.7 | 1.4 | 0.7 | 0.2 | 0.3 | 1.0 | 9.7 |

*Anticyclones.*—HIGHS were greater than the average in number, the Pacific highs being more frequent than usual, while the number of the Alberta type showed a deficit. The table hereunder shows the number of HIGHS by types.

*Highs.*

| | North Pacific. | South Pacific. | Alberta. | Plateau and Rocky Mountain Region. | Hudson Bay. | Total. |
|---|---|---|---|---|---|---|
| May, 1920 | 3.0 | 2.0 | 2.0 | 1.0 | 1.0 | 9.0 |
| Average number, 1892–1912 | 1.3 | 0.5 | 3.3 | 0.7 | 0.9 | 6.7 |

### THE WEATHER ELEMENTS.

By P. C. DAY, Climatologist and Chief of Division.

[Weather Bureau, Washington, July 1, 1920.]

#### PRESSURE AND WINDS.

With the approach of summer, pressure variations in the United States and Canada become less pronounced, the high and low areas have weaker gradients than during the colder months of the year, and their drift eastward is usually slower and along more northerly paths. May, 1920, was no exception to the general rule, save that the storm areas developed generally in lower latitudes and the HIGHS persisted for longer periods in the districts from the Great Lakes eastward, than is usual for that month. As a result, the monthly distribution was somewhat different from the normal over the more eastern districts, with averages highest along the International Boundary from the Dakotas eastward and lowest along the south Atlantic and Gulf coasts, the reverse of the normal distribution. West of the Great Plains the average pressure distribution was maintained along the usual lines, save that the high-pressure area over the North Pacific coast was more fully developed and the permanent warm-season depression over the lower Colorado River Valley was deeper than usual.

In the general absence of well-developed storm areas, the winds were not unusually high at any point and few stations reported velocities above 50 miles per hour, and severe local storms were much less frequent than during the two preceding months. The highest wind of the month along the middle and south Atlantic coasts was experienced on the 1st and 2d, and the only severe tornado of the month occurred on the 2d in Oklahoma, a full description of which appears in another portion of this issue.

The persistence of high pressure over the Great Lakes and eastward caused cool northerly winds during much of the month over the districts to eastward of the Mississippi River, this being particularly the case over the southeastern States. Between the Mississippi River and the Rocky Mountains the winds were mostly from the south. Along the Pacific coast they were generally from west to northwest.

#### TEMPERATURE.

The month opened with moderate temperatures in most sections of the country, but by the morning of the 3rd abnormally cold weather overspread the northern districts, with heavy to killing frosts in the Lake region and over the upper Ohio Valley, and temperatures were below freezing in the higher elevations of the Rocky Mountains. About the middle of the first decade increasing pressure over the Great Lakes caused a further lowering of the temperature in eastern districts and heavy to killing frosts were reported from the adjacent regions. Considerably warmer weather prevailed during the latter part of the decade in the north-central border districts, but moderately cold weather for the season continued in the Eastern States until near the close, when much warmer weather prevailed over that area, and by that time temperatures had gradually risen to above the seasonal average in nearly all sections of the country except in the far West.

During the early part of the second decade low temperatures for the season overspread most sections, and frosts occurred locally from the Lake region eastward. On the 13th a sharp drop in temperature occurred in the central Mississippi and Ohio Valleys, and by the middle of the month cool weather had overspread practically all districts east of the Mississippi River, with heavy frosts in many central and killing frosts in northern districts. For the next several days unseasonably cold weather continued in the central and northeastern States, and temperatures continued somewhat below normal in nearly all other sections of the country. However, during the remainder of the decade temperatures had a rising tendency and at the end they were near the normal, except in the far Northwest, where cooler weather had set in.

Toward the middle of the third decade much colder weather overspread the Northern Plains and Central Rocky Mountain States, and unseasonably low temperatures prevailed in the far Northwest, heavy to killing frosts occurring in eastern Oregon, Idaho, western Montana, and northwestern Wyoming, and lower temperatures also prevailed in the Atlantic Coast States. During the latter part of the month temperatures rose to or somewhat above the normal in most sections east of the Rocky Mountains, but it continued unseasonably cool in the far Northwest, with frosts and freezing temperatures in many localities.

The maximum temperatures were not unusually high, and the minima were not lower than the records of many other years, despite the generally cold character of the month over much of the country. The warmest days of the month were during the last decade as a rule, although the highest temperatures reported in Texas and Oklahoma, 106° and 102°, respectively, occurred on the 3d, and in portions of the Southwestern States on the 5th, and in the far Northwest on the 7th. In portions of California and generally in the Rocky Mountain States, as well as along the northern border from Lake Superior westward and in portions of the Mississippi Valley, the lowest temperatures of the month were recorded during the first few days, principally on the 1st, when temperatures as low as 10° were reported. However, the lowest recorded temperature of the month, 8°, occurred on the 4th in Wyoming. In the Southeastern States, the latter part of the first decade had the lowest temperatures of the month, while in much of the plains region and thence eastward to the Middle Atlantic States the coldest weather was near the middle of the second decade.

The month as a whole was decidedly colder than the normal over the Middle Atlantic States; in some portions the monthly averages were lower than in any preceding May of which there is official record. The month was likewise cold in the Ohio and Middle Mississippi Valleys, and thence westward to the Rocky Mountains and in the far Northwest. The monthly means were slightly above normal in the lower Mississippi Valley and thence westward over Texas and the far Southwest, and also along the northern border from Lake Superior to the eastern and northern portions of the Dakotas.

### PRECIPITATION.

Rain areas of wide extent were the exception during the month, although in some sections the rains were frequent and heavy. The most important rainy period during the month set in about the 10th, when a low-pressure area developed in the far Southwest and moved slowly into the middle plains region and thence eastward to the Atlantic coast. The precipitation attending this storm was well distributed over the central valleys and to the eastward and was copious to heavy in many districts. This was quickly followed by another rain area having its initial development in the same locality as the one referred to above. Its eastward progress was likewise slow; in fact, it can hardly be said to have had a distinctly progressive movement; but a rainy condition gradually overspread the central and eastern districts and some heavy falls resulted, particularly in Texas and Oklahoma, and thence eastward into the Mississippi Valley and portions of the Gulf and South Atlantic States. Some heavy rains occurred in New England near the beginning of the last decade, and a general rainy period set in over the plains region at the same time, some heavy falls occurring as it advanced northeastward to the Great Lakes. The greater part of the last decade was without general precipitation over extensive areas.

The total precipitation for the month was very generally less than normal, although no great shortage was experienced, save in restricted areas. In portions of the Middle and North Atlantic States, particularly in the Appalachian Mountain regions, the precipitation was far short of the usual amount for May. In some sections, particularly in the western portions of New York and Pennsylvania and in central North Carolina, the precipitation was the least ever known in May. Over the Pacific Coast States the monthly precipitation, though usually not heavy in May, was markedly deficient, due to the prevalence of high atmospheric pressure in the far Northwest, referred to previously. In such cases storms moving eastward from the North Pacific coast pass inland over British Columbia or southern Alaska instead of over Washington, Oregon, or northern California. As a result of this no storms entered the United States directly from the Pacific during the month and but little precipitation occurred. In the interior valleys of California the month was practically rainless, notably at Sacramento, where the month was entirely without rain, the second such occurrence during the month of May in the past 72 years.

In the Gulf States and portions of Texas, New York, Nebraska, and South Dakota the precipitation was frequently far above the normal and at times unusually heavy, causing damage by flood and otherwise. In some States unusual extremes occurred in the total falls for the month, notably in Oklahoma, where they ranged from less than 2 inches to nearly 18 inches, and in South Dakota where the range was from less than 1 inch to more than 10 inches.

### RELATIVE HUMIDITY.

The departure of the average relative humidity from normal was closely associated with the distribution of precipitation as is usually the case. In the middle and upper Mississippi Valley and thence eastward to the Great Lakes and New England, and southeastward to the middle Atlantic coast the average relative humidity was much less than normal, and similar conditions existed on the Pacific coast, where the relative dryness was at times very great, causing injury to plant growth in localities with insufficient ground moisture. In the middle and southern plains region and generally over the Gulf States relative humidity was in excess of the normal, frequently by a considerable percentage, particularly in Kansas and portions of surrounding States.

### LOCAL STORMS.

Tornadoes occurred in northeastern Oklahoma on May 2, causing about 70 deaths and injuring about 150 people, mostly at Peggs, which was practically obliterated (see Apr. REVIEW, p. 211). On May 7 a windstorm damaged trees and some buildings in Taylor, Tex.

# STORMS AND WARNINGS. WEATHER AND CROPS.

## STORMS AND WEATHER WARNINGS.

By H. C. FRANKENFIELD, Supervising Forecaster.

(Dated June 15, 1920.)

There were no general storms during the month, and but two local storm warnings were ordered. The first warnings were ordered on the morning of May 13 for the Atlantic coast from Point Judith, R. I., to Portsmouth, N. H. There was a moderate depression off the Virginia Capes, with an apparent northeastward movement, and strong NE. winds and probably gales were forecast for the afternoon and night following. Small craft warnings were also ordered to the southward as far as Delaware Breakwater, Del. The disturbance did not develop further, and only fresh to moderately strong winds occurred. The warnings were lowered at 9:30 p. m.

The second and last storm warning was ordered at 3:30 p. m., May 22, at which time the most pronounced disturbance of the month was over Minnesota, with some promise of further development. NE. warnings were ordered for Lake Superior and SW. warnings for Lakes Michigan and Huron. These warnings were partially verified as to Lakes Superior and Michigan, but failed on Lake Huron, as the storm moved rapidly off to the northnortheastward.

Several small craft warnings that were issued during the month were fully verified, and there were no storms without warning.

### FROST WARNINGS.

Frost warnings were issued on 12 days, and they were well verified as a rule, but owing to the lateness of the season the early warnings were not of great importance. The general frosts that occurred on the morning of the 3d over the Lake Region were not forecast, rain having been expected from a LOW of the southwestern type that did not move as rapidly as had been anticipated.

Special frost warnings for the cranberry region of New Jersey were issued on eight dates, and all but one were justified.

*Chicago, Ill, forecast district.*—No frosts of consequence occurred during May in the southern portion of the Chicago forecast district, and on account of the backwardness of the season warnings were not required until much later than usual from the northern Rocky Mountain States eastward to the Great Lakes.

Frost warnings were issued for Wyoming on the 24th, for portions of Wyoming and Montana on the 25th and 31st, and for the western and central portions of South Dakota and Nebraska on the 26th. These warnings were only partially verified.

In the cranberry bogs of Wisconsin warnings were not needed until near the middle of the month and were issued on only four days. On the 14th heavy to killing frost occurred without warning, due to a high-pressure area spreading southward over the upper Lake region with its crest over Wisconsin on the morning in question.—*Chas. L. Mitchell.*

*New Orleans, La., forecast district.*—Small craft warnings were issued for the Texas coast on May 11, 15, and 16, and were justified.

No general storm occurred on the coast without warnings.—*I. M. Cline.*

*Denver, Colo., forecast district.*—Special frost warnings were issued on the 1st for Utah and western Colorado, and on the 4th for the Grand Valley, Colo. The former was verified in western Colorado, but cloudiness prevailed in northern Utah, and the warning was only verified in part for the fruit districts of Utah. The warning of the 4th was verified at many stations in the Grand Valley and at two stations the temperature dropped nearly to the freezing point. A warning of freezing temperature was sent out on the 14th for localities in the Gunnison Valley which was not technically verified, although the temperature fell at several stations and nearly reached 32° at one station. Warnings of light frost were issued on the 15th for localities in Colorado and on the 18th and 26th for Gunnison Valley. Those of the 18th were partially verified and that of the 26th completely.—*A. H. Thiessen.*

*San Francisco, Calif., forecast district.*—Frosts occurred frequently in the north Pacific States, except near the coast, and in the plateau region. Frost warnings were issued in Washington 11 times, in Oregon and Idaho 13, and in Nevada 14. It is believed that the warnings were in all cases justified and that no damaging frost occurred without warnings.

Live-stock warnings were issued in eastern Washington on the 8th and in eastern Oregon, Idaho, and Nevada on the 8th and 21st.

Fire-weather warnings were issued in northwestern Oregon on the 18th, and in California and Nevada on the 18th and 26th. Both live-stock and fire-weather warnings were justified.

Southwest storm warnings were issued at the mouth of the Columbia River and Washington stations on the 16th and northwest warnings at Point Reyes on the 21st, and were generally verified.

The high winds at Tatoosh Island and the Puget Sound stations on the 20th were not forecast, as the report was missing from Tatoosh Island on that date, and the other reports received did not indicate the conditions off Vancouver Island at that time.—*G. H. Willson.*

## RIVERS AND FLOODS, MAY, 1920,

By ALFRED J. HENRY, Meteorologist.

The floods in progress in the Ohio and Mississippi and their tributaries at the close of April continued into May, and in the case of the lower Mississippi into June.

Floods which arose and receded wholly within the month of May were confined to the Gulf drainage, the rivers of southern Indiana, Arkansas, and the rivers of northern Louisiana draining into the Mississippi.

The most noteworthy of these floods occurred in the Tombigbee and Black Warrior Rivers of Alabama and Mississippi, the Red River of Texas-Louisiana, and the Trinity River of Texas. The usual details as to dates and crests reached will be found in the table which concludes this report.

The most serious result of these floods was the overflow of bottom lands at a time when farming operations should have been in progress. The deposits of silt on agricultural lands is, of course, a clear benefit; but, on the other hand, the time between planting and harvesting has been so much reduced in localities that there is some doubt as to whether a crop can be secured.

### THE 1920 FLOOD IN THE MISSISSIPPI RIVER.

It will be convenient to consider the flood in the upper Mississippi as separate and distinct from that in the river below Cairo, Ill.

*Upper Mississippi.*—The melting of the accumulated snowfall of the winter in Minnesota and Wisconsin began rather suddenly in the latter part of March. The river at St. Paul was frozen until March 14, when the ice in the channel broke at a stage of 1.5 feet. The water from melting snow began to reach the rivers on the 16th, and there was a rather steady inflow until the 29th, when a crest stage of 13.6 feet was reached. The river fell very little on the 30th and 31st. A general rainstorm then passed across the watershed on April 1–2, adding materially to the flood flow in tributary streams and increasing the flood peak in the Mississippi so that by the 7th, when Dubuque was reached, a serious flood was in progress. The breaking of the levees at Muscatine, Iowa, caused the crest to move less rapidly and to diminish in magnitude. The Dubuque flood flattened out after reaching Keokuk, Iowa; meantime a third rainstorm of 48 hours' duration over Iowa, Wisconsin, and Illinois started a rise out of the streams of those States, which, reaching the Mississippi, then at a high stage, caused a second crest on that stream, beginning at Warsaw, Ill., on the 21st and reaching Alton, Ill., on the 24th. The Mississippi between Alton and Chester, Ill., did not reach the flood stage, and the only effect of the upper Mississippi water on the river below Cairo was to prolong the high stages then existing.

*Lower Mississippi.*—As previously noted (last REVIEW **48**:234-236), the Mississippi at Cairo and below at the end of April was in flood. It fell to and below the flood stage at Cairo May 9, to below flood stage at Memphis on the 14th, Helena on the 18th, Greenville, Miss., on the 25th, and the end of the month remained above flood stage from Vicksburg to the mouth. It passed below flood stage at Vicksburg on June 13 and at New Orleans on June 23, thus concluding the most prolonged period of high water below Memphis ever before recorded. The flood was confined within the levees except for a small break about 75 miles below New Orleans that was soon closed.

There was some overflow from backwater in the lower St. Francis, the lower White and the lower Black River Valleys. Railroad traffic was not materially interrupted. In the overflowed regions planting was delayed and the season for maturing cotton and other crops has of course been shortened.

The following additional information was received subsequent to the preparation of the foregoing paragraph.

### THE CAIRO DISTRICT.

* * * In the upper portions of the district, the floods receded in time for spring farm work, so that the losses of prospective crops were small. But as the waters reached the main stream at Cairo, the increments received one by one from the various tributaries and at times simultaneously from several sources served to produce a mighty stream, that took a long time to run off. On account of the long duration of the rise, the losses are much greater than they would have been otherwise.

The comparative table below shows the crest stages and durations of all floods at Cairo in which a stage of over 50 feet has been recorded.

| Year. | Crest. | Date. | Days above flood stage. | Last date above flood stage. | Days above 40 feet. | Last date. |
|---|---|---|---|---|---|---|
| 1882 | 51.9 | Feb. 25, 26 | 57 | Mar. 21 | 108 | June 11 |
| 1883 | 52.2 | Feb. 26, 27 | [1] 22 | Mar. 8 | 55 | May 4 |
| 1884 | 51.8 | Feb. 21-24 | 43 | Apr. 6 | 58 | Apr. 11 |
| 1886 | 51.0 | Apr. 18, 19 | [1] 22 | Apr. 25 | [1] 27 | Apr. 27 |
| 1897 | 51.7 | Mar. 25-28 | [1] 49 | Apr. 22 | [1] 59 | Apr. 27 |
| 1903 | 50.6 | Mar. 15-17 | 27 | Apr. 25 | 80 | June 19 |
| 1907 | 50.4 | Jan. 27 | 25 | Mar. 29 | 53 | Apr. 3 |
| 1912 | 54.0 | Apr. 6, 7 | 48 | May 13 | 68 | May 17 |
| 1913 | 54.8 | Apr. 4, 7 | 48 | Apr. 22 | 63 | Apr. 25 |
| 1916 | 53.4 | Feb. 4 | [1] 43 | Feb. 16 | 67 | Apr. 15 |
| 1920 | 51.4 | Mar. 31 | 45 | May 8 | 64 | May 27 |

[1] Continuous; others are in two or more periods.

From the above table it is seen that the river remained above flood stage at Cairo till May 8th and above 40 feet till May 27, though not continuously so. There is considerable land below Cairo that overflows with a 40-foot stage at Cairo.

The long duration of the high water caused peculiarly distressing conditions in the Cairo drainage district, a leveed district just outside the northern limits of the city. Failure of the drainage pumps, or financial inability to operate them, caused a gradual rise of the seep water in the district, and the flooding for two months or more of a settlement of working people known locally as Future City, to a depth of from 1 to 3 feet. The track of the interurban railway was under water for a short distance. This is the first time in recent years that this area has ever been flooded without the breaking of levees, as in 1912 and 1913, when the entire district was submerged to a depth of 12 to 20 feet * * *.—*W. E. Barron.*

*Estimated loss due to floods.*

| District and river. | Tangible property, bridges, roads, buildings, and levees. | Crops. | | Farm machinery, live stock, cord-wood. | Suspension of business. | Estimated value of warnings. |
|---|---|---|---|---|---|---|
| | | Matured. | Prospective. | | | |
| Houston, Tex.: | | | | | | |
| Guadalupe [1] | | | $85,000 | $2,000 | | $25,000 |
| Trinity | $5,000 | $13,500 | 1,217,000 | 3,500 | $6,000 | 80,800 |
| Dallas, Tex.: | | | | | | |
| Trinity | 50,000 | 3,000 | 701,500 | 70,000 | 42,000 | 145,000 |
| Shreveport, La.: | | | | | | |
| Red | 150,000 | | 675,000 | 15,000 | 200,000 | 150,000 |
| Memphis, Tenn.: | | | | | | |
| Mississippi | 20,000 | | 100,000 | | 300,000 | 75,000 |
| Terre Haute, Ind.: | | | | | | |
| Wabash | | | | | 3,000 | 15,000 |
| Mobile, Ala.: | | | | | | |
| Tombigbee | | | 32,000 | 4,300 | 3,300 | 8,600 |
| Cairo, Ill.: | | | | | | |
| Mississippi | 195,000 | 36,000 | 1,402,000 | [2] 104,350 | 240,000 | 957,000 |
| Total | 420,000 | 52,500 | 4,202,000 | 199,150 | 794,300 | 1,456,400 |

[1] Acres overflowed: Guadalupe, 15,000; Trinity, 8,000—due to failure of levee.
[2] Add $56,700 as cost of feeding stock removed from ranges.

*Flood stages for the month of May, 1920.*

| River and station. | Flood stage. | Above flood stages—dates. From— | To— | Crest. Stage. | Date. |
|---|---|---|---|---|---|
| ATLANTIC DRAINAGE. | | | | | |
| *Connecticut:* | *Feet.* | | | *Feet.* | |
| White River Junction, Vt. | 13 | (1) | 2 | 18.4 | [2]24 |
| Hartford, Conn. | 16 | (1) | 2 | 20.2 | [2]16 |
| *Santee:* | | | | | |
| Rimini, S. C. | 12 | (1) | 4 | 17.2 | [2]9,10 |
| Ferguson, S. C. | 12 | (1) | 8 | 14.0 | [2]3 |
| *Ocmulgee:* | | | | | |
| Abbeyville, Ga. | 11 | 5 | 6 | 11.3 | 5,6 |
| Do | 11 | 9 | 12 | 12.0 | 10,11 |
| EAST GULF DRAINAGE. | | | | | |
| *Apalachicola:* | | | | | |
| Blountstown, Fla. | 15 | (1) | 3 | 16.0 | 2 |
| Do | 15 | 6 | 11 | 16.8 | 8 |
| Do | 15 | 13 | 13 | 15.5 | 13 |
| Do | 15 | 17 | 18 | 15.2 | 18 |
| River Junction, Fla. | 12 | (1) | 25 | 23.4 | [2]7 |
| *Chattahoochee:* | | | | | |
| Alaga, Ala. | 30 | 6 | 7 | 33.1 | 6 |
| *Alabama:* | | | | | |
| Selma, Ala. | 35 | (1) | 1 | 37.4 | [2]30 |
| *Tombigbee:* | | | | | |
| Demopolis, Ala. | 39 | (1) | 11 | 61.6 | [2]10 |
| Do | 39 | 18 | 22 | 41.4 | 19,20 |
| *Black Warrior:* | | | | | |
| Tuscaloosa, Ala. | 46 | 14 | 15 | 48.7 | 15 |
| *Pearl:* | | | | | |
| Jackson, Miss. | 20 | (1) | 10 | 25.0 | 7 |
| Columbia, Miss. | 18 | (1) | 5 | 22.8 | 1 |
| *West Pearl:* | | | | | |
| Pearl River, La. | 13 | (1) | 12 | 15.3 | 7 |
| Do | 13 | 21 | 22 | 13.2 | 22 |
| MISSISSIPPI DRAINAGE. | | | | | |
| *Ohio:* | | | | | |
| Henderson, Ky. | 33 | (1) | 3 | 39.1 | [2]28,29 |
| Evansville, Ind. | 35 | (1) | 2 | 40.8 | [2]28 |
| Mount Vernon, Ind. | 35 | (1) | 4 | 40.5 | [2]29 |
| Shawneetown, Ill. | 35 | (1) | 5 | 43.4 | 1 |
| Cairo, Ill. | 45 | (1) | 8 | 49.5 | 1,2 |
| *Green:* | | | | | |
| Lock No. 2, Rumsey, Ky. | 34 | (1) | 2 | 35.5 | 29,30 |
| *Wabash:* | | | | | |
| Vincennes, Ind. | 14 | (1) | 2 | 20.0 | [2]26 |
| Mount Carmel, Ill. | 15 | (1) | 4 | 23.6 | [2]28,29 |
| Do | 15 | 15 | 25 | 18.3 | 20 |
| *White:* | | | | | |
| Decker, Ind. | 18 | (1) | 1 | 24.0 | [2]28 |
| Do | 18 | 19 | 20 | 18.1 | 19 |
| *West Fork White:* | | | | | |
| Elliston, Ind. | 19 | 14 | 15 | 21.3 | 15 |
| *Mississippi:* | | | | | |
| Hannibal, Mo. | 13 | (1) | 4 | 19.5 | [2]22 |
| Do | 13 | 13 | 19 | 14.7 | 14 |
| Louisiana, Mo. | 12 | (1) | 5 | 17.5 | [2]23 |
| Do | 12 | 13 | 18 | 13.7 | 14 |
| Grafton, Ill. | 18 | (1) | 7 | 22.4 | [2]25 |
| Do | 18 | 14 | 22 | 19.0 | 17,18 |
| Alton, Ill. | 21 | (1) | 7 | 25.1 | [2]24 |
| Do | 21 | 17 | 25 | 22.9 | 22 |
| Chester, Ill. | 27 | 21 | 25 | 27.8 | 22,23 |
| Cape Girardeau, Mo. | 30 | 20 | 27 | 31.7 | 23,24 |
| New Madrid, Mo. | 34 | (1) | 10 | 38.6 | 3 |
| Memphis, Tenn. | 35 | (1) | 13 | 40.3 | [2]5 |
| Helena, Ark. | 42 | (1) | 18 | 50.1 | [2]8,9 |
| Do | 42 | 27 | 30 | 42.3 | 29 |
| Arkansas City, Ark. | 42 | (1) | (3) | 54.0 | [2]11 |
| Greenville, Miss. | 42 | (1) | 24 | 47.0 | [2]16 |
| Vicksburg, Miss. | 45 | (1) | (3) | 50.8 | [2]19–28 |
| Natchez, Miss. | 46 | (1) | (3) | 51.5 | [2]28 |
| Baton Rouge, La. | 35 | (1) | (3) | 41.5 | 22,24,25 |
| Donaldsonville, La. | 28 | (1) | (3) | 32.6 | 18,19, 23–25 |
| New Orleans, La. | 18 | (1) | (3) | 20.4 | 17,18 |
| *Des Moines:* | | | | | |
| Tracy, Iowa. | 14 | 14 | 15 | 14.4 | 14 |
| Ottumwa, Iowa. | 10 | 13 | 16 | 11.4 | 15 |
| *Illinois:* | | | | | |
| Peru, Ill. | 14 | (1) | 28 | 22.0 | [2]23 |
| Henry, Ill. | 7 | (1) | (3) | 16.2 | [2]24 |
| Peoria, Ill. | 16 | (1) | 30 | 22.9 | [2]25 |
| Havana, Ill. | 14 | (1) | (3) | 19.7 | [2]26–28 |
| Beardstown, Ill. | 12 | (1) | (3) | 21.3 | [2]27 |
| Pearl, Ill. | 12 | (1) | (3) | 19.1 | [2]27 |
| *Missouri:* | | | | | |
| Running Water, S. Dak. | 16 | 15 | 15 | 16.0 | 15 |
| Blair, Nebr. | 16 | 16 | 18 | 17.8 | 18 |
| Omaha, Nebr. | 19 | 18 | 18 | 19.5 | 18 |
| St. Joseph, Mo. | 12 | 19 | 21 | 12.7 | 20 |
| Kansas City, Mo. | 22 | 20 | 21 | 22.6 | 21 |
| St. Charles, Mo. | 25 | 21 | 25 | 26.0 | 21 |
| *James:* | | | | | |
| Huron, S. Dak. | 9 | 13 | 20 | 10.9 | 13 |
| *Grand:* | | | | | |
| Brunswick, Mo. | 10 | 4 | 4 | 10.0 | 4 |
| Do | 10 | 16 | (3) | 13.1 | 22 |
| *Meramec:* | | | | | |
| Pacific, Mo. | 11 | 21 | 23 | 16.7 | 22 |
| Glencoe, Mo. | 15 | 22 | 22 | 20.2 | 22 |
| Valley Park, Mo. | 14 | 19 | 19 | 15.0 | 19 |
| Do | 14 | 21 | 23 | 22.2 | 23 |

[1] Continued from April. [2] April. [3] Continued into June.

*Flood stages for the month of May, 1920*—Continued.

| River and station. | Flood stage. | Above flood stages—dates. From— | To— | Crest. Stage. | Date. |
|---|---|---|---|---|---|
| MISSISSIPPI DRAINAGE—continued. | | | | | |
| *Bourbeuse:* | *Feet.* | | | *Feet.* | |
| Union, Mo. | 10 | 21 | 22 | 15.2 | 22 |
| *Yazoo:* | | | | | |
| Greenwood, Miss. | 36 | 5 | 13 | 36.9 | 7,8 |
| Do | 36 | 18 | 29 | 36.8 | 19–21 |
| Yazoo City, Miss. | 25 | (1) | (3) | 31.0 | 19–21 |
| *Tallahatchie:* | | | | | |
| Swan Lake, Miss. | 25 | (1) | (3) | 29.1 | 3–7 |
| *Ouachita:* | | | | | |
| Arkadelphia, Ark. | 18 | 12 | 14 | 22.6 | 12 |
| Do | 18 | 17 | 18 | 20.2 | 17 |
| Camden, Ark. | 30 | (1) | 4 | 36.0 | 1 |
| Do | 30 | 15 | 24 | 38.8 | 17 |
| Monroe, La. | 40 | 29 | (3) | 40.3 | 31 |
| *White:* | | | | | |
| Calico Rock, Ark. | 18 | 6 | 6 | 20.5 | 6 |
| Do | 18 | 22 | 23 | 24.3 | 22 |
| Batesville, Ark. | 23 | 6 | 7 | 25.9 | 6 |
| Do | 23 | 23 | 24 | 29.2 | 23 |
| Newport, Ark. | 26 | 24 | 25 | 26.9 | 25 |
| Georgetown, Ark. | 22 | 11 | 22 | 23.2 | 14 |
| Do | 22 | 25 | (3) | 23.0 | 28 |
| *Black:* | | | | | |
| Black Rock, Ark. | 14 | 6 | 6 | 14.0 | 6 |
| Do | 14 | 18 | (3) | 18.9 | 22 |
| *Cache:* | | | | | |
| Patterson, Ark. | 9 | 13 | (3) | 10.2 | 18–20 |
| *Red:* | | | | | |
| Alexandria, La. | 36 | 29 | (3) | 36.7 | 31 |
| Index, Tex. | 27 | 14 | 14 | 27.0 | 14 |
| Do | 27 | 19 | 21 | 27.6 | 21 |
| Fulton, Ark. | 28 | 14 | 25 | 33.6 | 18,19 |
| Springbank, Ark. | 37 | 20 | 28 | 41.4 | 23 |
| *Little:* | | | | | |
| Whitecliffs, Ark. | 28 | 13 | 20 | 30.0 | 14,18 |
| *Sulphur:* | | | | | |
| Finlay, Tex. | 24 | 14 | 24 | 29.2 | 17 |
| Ringo Crossing, Tex. | 20 | 8 | 21 | 29.5 | 13 |
| *Cypress:* | | | | | |
| Jefferson, Tex. | 18 | 21 | 23 | 19.2 | 22 |
| WEST GULF DRAINAGE. | | | | | |
| *Atchafalaya:* | | | | | |
| Simmesport, La. | 41 | (1) | (3) | 46.7 | 21–28 |
| Melville, La. | 37 | (1) | (3) | 42.5 | 20–26 |
| *Trinity:* | | | | | |
| Fort Worth, Tex. | 20 | 10 | 12 | 29.9 | 11 |
| Do | 20 | 15 | 20 | 26.0 | 16 |
| Dallas, Tex. | 25 | 6 | 24 | 39.7 | 12 |
| Trinidad, Tex. | 28 | 10 | (3) | 41.5 | 18 |
| Long Lake, Tex. | 40 | 20 | 24 | 45.9 | 22 |
| Liberty, Tex. | 25 | 30 | (3) | 25.4 | 31 |
| *Guadalupe:* | | | | | |
| Gonzales, Tex. | 22 | 16 | 18 | 33.4 | 16 |
| Victoria, Tex. | 16 | 17 | 22 | 24.6 | 20 |
| PACIFIC DRAINAGE. | | | | | |
| *Kings:* | | | | | |
| Piedra, Calif. | 12 | 19 | 22 | 13.9 | 20 |

[1] Continued from April. [2] April. [3] Continued into June.

## MEAN LAKE LEVELS DURING MAY, 1920.

By UNITED STATES LAKE SURVEY.

[Dated: Detroit, Mich., June 4, 1920.]

The following data are reported in the "Notice to Mariners" of the above date:

| Data. | Lakes.* Superior. | Michigan and Huron. | Erie. | Ontario. |
|---|---|---|---|---|
| Mean level during May, 1920: | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Above mean sea level at New York | 602.40 | 580.75 | 572.31 | 245.60 |
| Above or below— | | | | |
| Mean stage of April, 1920 | +0.14 | +0.21 | +0.67 | +0.05 |
| Mean stage of May, 1919 | +0.20 | −0.63 | −1.37 | −1.67 |
| Average stage for May last 10 years | +0.44 | +0.17 | −0.42 | −1.10 |
| Highest recorded May stage | −0.65 | −2.77 | −2.11 | −3.35 |
| Lowest recorded May stage | +1.58 | +1.19 | +1.00 | +0.64 |
| Average relation of the May level to— | | | | |
| April level | ..... | +0.3 | +0.3 | +0.3 |
| June level | ..... | −0.3 | −0.2 | −0.2 |

* Lake St. Clair's level: In May, 575.24 feet.

## EFFECT OF WEATHER ON CROPS AND FARMING OPERATIONS, MAY, 1920.

By J. WARREN SMITH, Meteorologist in Charge.

The weather during the first decade of May was much more favorable for the growth of vegetation and farm work than had theretofore prevailed in most parts of the United States. It continued too cool, however, in the Eastern States for best growth, and more moisture was needed in some far western districts, but the general rains in the lower Great Plains and much of Texas were very beneficial. Corn planting made, mostly, favorable advance, although it was rather cool in most Southern States for good growth, and planting was delayed in parts of the Ohio Valley, on account of wet soil. The rainfall in the western portion of the cotton belt was beneficial, but it continued too wet and cool in the southeastern cotton districts and planting was very backward in that section. Winter wheat made steady improvement in the principal producing area, although the advance was not so satisfactory in much of the Ohio Valley. Much better weather prevailed during this period in the spring wheat belt, and rapid progress was made in seeding; a general improvement was reported in pastures, meadows, and ranges, and in most sections in truck also.

Much of the second decade of the month was too cool in the Central and Eastern States for warm-weather crops, but more favorable temperatures prevailed in the extreme West. Planting corn was further delayed in the middle and upper Mississippi and lower Ohio Valleys on account of continued wet soil. It was generally unfavorable for cotton in the eastern portion of the belt, on account of persistent cool nights, but the rainfall in southern and western Texas was highly beneficial, and cotton made very good progress in that State. Winter wheat continued to improve under favorable weather conditions, while spring wheat made satisfactory advance. There was also some improvement in oats and barley but growth was generally slow, while potatoes, pastures, and meadows made favorable advance in all sections.

The last decade of the month was favorable for the growth of vegetation in most sections of the country, although it was much too cool in the far Northwest, where some frost damage occurred. Farm work made rapid progress under favorable weather conditions, except locally in some interior districts, where delayed by rain or wet soil. The period was generally favorable for the growth of corn in central and southern districts, and while cotton made steady improvement generally, it was too cool the latter part of the month in the more eastern districts and too cool and wet for best results in the extreme western portion of the belt. Winter wheat continued to improve, and spring wheat made good progress under favorable weather conditions. Grass and truck crops were favorably affected, except that it was too cool in the Northwest.

416—20——4

# CLIMATOLOGICAL TABLES.*

## CONDENSED CLIMATOLOGICAL SUMMARY.

In the following table are given for the various sections of the climatological service of the Weather Bureau the monthly average temperature and total rainfall; the stations reporting the highest and lowest temperatures, with dates of occurrence; the stations reporting the greatest and least total precipitation; and other data as indicated by the several headings.

The mean temperature for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperatures and precipitations are based only on records from stations that have 10 or more years of observations. Of course the number of such records is smaller than the total number of stations.

*Condensed climatological summary of temperature and precipitation by sections, May, 1920.*

| Section. | Temperature. | | | | | | | | Precipitation. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Section average. | Departure from the normal. | Monthly extremes. | | | | | | Section average. | Departure from the normal. | Greatest monthly. | | Least monthly. | |
| | | | Station. | Highest. | Date. | Station. | Lowest. | Date. | | | Station. | Amount. | Station. | Amount. |
| | °F. | °F. | | °F. | | | °F. | | In. | In. | | In. | | In. |
| Alabama | 70.7 | −1.0 | Spring Hill | 97 | 24 | Centerville | 41 | 9 | 4.92 | +0.88 | Guin | 11.57 | Healing Springs | 2.05 |
| Arizona | 66.5 | +1.2 | Gila Bend | 109 | 19 | Seligman | 20 | 3 | 0.37 | +0.02 | Ash Fork | 1.92 | 9 stations | 0.00 |
| Arkansas | 70.8 | +1.8 | 2 stations | 96 | 24† | Nail | 39 | 14 | 8.17 | +2.86 | Marshall | 15.32 | Ft. Smith | 2.12 |
| California | 61.7 | −0.4 | Greenland Ranch | 114 | 19 | Portola | 16 | 1 | 0.18 | −1.04 | Squirrel Inn | 2.34 | 123 stations | 0.00 |
| Colorado | 52.2 | +0.9 | Greeley | 96 | 29 | 3 stations | 10 | 1† | 1.73 | −0.11 | Palisade Lake | 4.80 | 2 stations | T. |
| Florida | 74.4 | −1.6 | Bonifay | 97 | 24 | Glen St. Mary | 47 | 10 | 4.98 | +1.09 | Homestead | 14.90 | Fort Myers | 1.14 |
| Georgia | 69.6 | −2.2 | Quitman | 98 | 23 | 4 stations | 40 | 9† | 4.51 | +1.29 | Newnan | 8.22 | Waynesboro | 2.05 |
| Hawaii (April) | 70.5 | +0.7 | Mahukona | 90 | 19 | 2 stations | 49 | 6† | 3.62 | −3.85 | Honomu | 13.51 | Puuhele | 0.13 |
| Idaho | 50.6 | −1.4 | Wendell | 89 | 18 | Blackfoot Dam | 12 | 1 | 1.10 | −0.71 | Prichard | 3.45 | Jerome | 0.00 |
| Illinois | 61.4 | −1.4 | 3 stations | 91 | 23† | Mt. Carroll | 28 | 14 | 4.99 | +0.92 | Anna | 9.65 | Antioch | 1.16 |
| Indiana | 60.4 | −2.1 | 2 stations | 92 | 23 | Hobart | 28 | 15 | 3.58 | −0.47 | Mount Vernon | 5.71 | Angola | 1.78 |
| Iowa | 59.4 | −1.1 | 3 stations | 89 | 22† | 2 stations | 29 | 14 | 3.26 | −1.31 | Keosauqua | 5.73 | Fort Dodge | 0.62 |
| Kansas | 63.2 | 0.0 | 2 stations | 96 | 25† | 5 stations | 32 | 13† | 3.11 | −0.86 | Walnut | 7.60 | Randolph | 1.18 |
| Kentucky | 64.2 | −1.4 | 2 stations | 94 | 23 | Beattyville | 32 | 15 | 4.08 | +0.13 | Princeton | 7.24 | Middlesboro | 2.03 |
| Louisiana | 76.5 | +2.6 | Angola | 100 | 25 | Calhoun | 49 | 15 | 4.44 | +0.34 | Calhoun | 8.51 | Paradise | 1.15 |
| Maryland-Delaware | 58.7 | −4.3 | Cumberland, Md | 91 | 28 | Oakland, Md | 22 | 16 | 2.01 | −1.54 | Coleman, Md | 3.00 | Crisfield, Md | 0.70 |
| Michigan | 52.6 | −1.1 | Howard City | 93 | 26† | Bergland | 12 | 12 | 1.40 | −1.91 | Reed City | 2.59 | Port Austin | 0.22 |
| Minnesota | 55.6 | +1.2 | Maple Plains | 90 | 25 | 3 stations | 19 | 1 | 3.14 | −0.35 | Hinckley | 6.53 | Fairvault | 1.01 |
| Mississippi | 73.2 | +1.5 | Pontotoc | 99 | 22 | Booneville | 44 | 1 | 5.86 | +1.14 | Swan Lake | 11.52 | Monticello | 2.30 |
| Missouri | 63.8 | −0.8 | Caruthersville | 97 | 22† | 2 stations | 32 | 1† | 4.85 | +0.04 | Farmington | 10.15 | Edgerton | 1.47 |
| Montana | | | | | | | | | | | | | | |
| Nebraska | 57.9 | −1.1 | Lodgepole | 93 | 24 | Gordon | 29 | 23 | 3.55 | −0.06 | Ainsworth | 9.23 | Holdrege | 0.80 |
| Nevada | 56.2 | +1.4 | Logandale | 105 | 20 | San Jocinto | 16 | 26 | 0.45 | −0.44 | Sharp | 1.66 | 2 stations | 0.00 |
| New England | 52.6 | −2.4 | Vernon, Vt | 92 | 28 | Orono, Me | 5 | 9 | 2.85 | −0.54 | Blue Hill, Mass | 7.55 | Berlin, N. H | 0.74 |
| New Jersey | 57.4 | −3.0 | Imlaystown | 89 | 28 | Culvers Lake | 25 | 5† | 3.00 | −0.83 | Tuckerton | 5.23 | Atlantic City | 1.61 |
| New Mexico | 59.6 | +0.5 | Artesia | 104 | 20 | Luna | 18 | 6 | 1.58 | +0.47 | Las Vegas | 4.70 | 9 stations | 0.00 |
| New York | 54.1 | −2.0 | Troy | 90 | 30 | Indian Lake | 18 | 5 | 1.64 | −2.04 | Scarsdale | 4.76 | Palermo | 0.10 |
| North Carolina | 62.5 | −4.3 | Goldsboro | 92 | 12 | 3 stations | 26 | 6† | 1.85 | −2.41 | Andrews | 5.50 | Edenton | 0.16 |
| North Dakota | 54.0 | +1.4 | Howard | 89 | 21 | 2 stations | 20 | 1 | 1.70 | −0.85 | 2 stations | 3.78 | Dunseith | 0.56 |
| Ohio | 58.3 | −2.6 | 2 stations | 94 | 30† | 4 stations | 25 | 15 | 2.45 | −1.36 | Kings Mills | 5.05 | Upper Sandusky | 0.65 |
| Oklahoma | 69.0 | +1.2 | Ardmore | 102 | 3 | 2 stations | 36 | 15† | 5.33 | −0.05 | Hugo | 17.66 | Hurley | 1.89 |
| Oregon | 51.9 | −1.9 | Echo | 90 | 7 | Anna Spring | 8 | 25 | 0.85 | −1.33 | Cornucopia | 3.10 | Fremont | T. |
| Pennsylvania | 56.6 | −3.2 | Indiana | 92 | 30 | West Bingham | 18 | 5 | 2.02 | −1.81 | Uniontown | 3.65 | Creekside | 0.67 |
| Porto Rico | 77.8 | +0.6 | Canovanas | 99 | 5 | Aibonito | 51 | 9 | 6.20 | −0.83 | Inabon Falls | 20.10 | Cangrejo | 1.57 |
| South Carolina | 67.6 | −3.7 | Bowman | 95 | 5 | 5 stations | 42 | 7† | 1.77 | −1.69 | Calhoun Falls | 4.77 | Orangeburg | 0.30 |
| South Dakota | 55.6 | +0.2 | Colome | 97 | 25 | Spearfish | 20 | 4 | 4.79 | +1.69 | Vale | 10.25 | White Lake | 1.24 |
| Tennessee | 66.8 | −0.4 | 2 stations | 93 | 22† | Mountain City | 27 | 15 | 4.25 | +0.20 | Waynesboro | 9.41 | Greenville (near) | 1.15 |
| Texas | 74.3 | +1.3 | Encinal | 106 | 3 | 2 stations | 37 | 15 | 5.11 | +1.43 | Arthur City | 17.45 | Clint | T. |
| Utah | 55.0 | +0.1 | St. George | 99 | 20 | Blacks Fork | 12 | 6 | 1.35 | +0.03 | High Line City Creek | 5.09 | Midlake | 0.00 |
| Virginia | 59.9 | −5.1 | Mineral | 92 | 18 | Burkes Garden | 22 | 15 | 1.87 | −1.97 | Lawrenceville | 4.30 | Onley | 0.50 |
| Washington | 51.6 | −2.9 | Rimrock | 92 | 17 | Paradise Inn | 20 | 22 | 1.24 | −0.95 | Quinlault | 6.87 | Trinidad | 0.00 |
| West Virginia | 58.9 | −3.3 | Glenville | 95 | 31 | 2 stations | 24 | 16† | 2.76 | −1.33 | Glenville | 6.97 | Burlington | 1.08 |
| Wisconsin | 54.2 | −0.6 | Grand Rapids | 92 | 31 | Deerskin Dam | 14 | 1 | 2.53 | −1.49 | Superior | 4.73 | Plum Island | 0.40 |
| Wyoming | 48.9 | −0.3 | Wheatland | 93 | 29 | Moran | 8 | 4 | 2.43 | +0.29 | Knowles | 8.17 | Hyattville | 0.24 |

* For description of tables and charts see this REVIEW, Jan., 1920, p. 54.

† Other dates also.

TABLE I.—*Climatological data for Weather Bureau Stations, May, 1920.*

| Districts and stations. | Elevation of instrument. | | | Pressure. | | | Temperature of the air. | | | | | | | | | | | | Mean wet thermometer. | Mean temperature of the dew-point. | Mean relative humidity. | Precipitation. | | | Wind. | | | | Clear days. | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow, sleet, and ice on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 21 hours. | Departure from normal. | Mean max.+mean min.÷2 | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | | | | Total. | Departure from normal. | Days with 0.01 inch or more. | Total movement. | Prevailing direction. | Maximum velocity. Miles per hour | Maximum velocity. Direction. | Maximum velocity. Date. | | | | | |
| | *Ft.* | *Ft.* | *Ft.* | *In.* | *In.* | *In.* | ° *F.* | ° *F.* | °*F.* | | °*F.* | °*F.* | | °*F.* | °*F.* | °*F.* | °*F.* | % | *In.* | *In.* | | *Miles.* | | | | | | *0–10* | *In.* | *In.* |
| *New England.* | | | | | | | **52.6** | **− 2.0** | | | | | | | | | | **75** | **3.22** | **− 0.1** | | | | | | | | | | **5.9** | | |
| Eastport | 76 | 67 | 85 | 29.97 | 30.05 | +0.09 | 47.0 | + 0.1 | 74 | 17 | 55 | 30 | 5 | 39 | 33 | 43 | 38 | 75 | 1.26 | − 2.5 | 5 | 6,394 | s. | 42 | se. | 9 | 8 | 9 | 14 | 6.2 | 4.2 | 0.0 |
| Greenville, Me | 1,070 | 6 | .... | 28.88 | 30.05 | ..... | 50.0 | ..... | 83 | 27 | 64 | 23 | 5 | 36 | 47 | ..... | ..... | ..... | 1.33 | ..... | 8 | ..... | ..... | ..... | ..... | 16 | 3 | 12 | ..... | 0.2 | 0.0 |
| Portland, Me | 103 | 82 | 117 | 29.95 | 30.07 | + .10 | 51.2 | − 2.3 | 73 | 29 | 58 | 32 | 5 | 44 | 22 | 46 | 40 | 71 | 3.23 | − 0.4 | 8 | 6,288 | s. | 31 | se. | 8 | 11 | 7 | 13 | 5.2 | 0.0 | 0.0 |
| Concord | 288 | 70 | 79 | 29.75 | 30.06 | + .08 | 54.1 | − 1.6 | 88 | 28 | 65 | 31 | 5 | 43 | 38 | ..... | ..... | ..... | 2.50 | − 0.7 | 6 | 3,065 | se. | 15 | w. | 10 | 10 | 8 | 13 | 6.0 | 0.0 | 0.0 |
| Burlington | 404 | 11 | 48 | 29.61 | 30.05 | + .08 | 54.1 | + 0.2 | 81 | 27 | 64 | 29 | 5 | 44 | 35 | ..... | ..... | ..... | 1.74 | − 1.1 | 10 | 6,437 | s. | 34 | nw. | 10 | 8 | 12 | 11 | 5.8 | 0.0 | 0.0 |
| Northfield | 876 | 12 | 60 | 29.11 | 30.07 | + .10 | 50.1 | − 3.4 | 85 | 27 | 64 | 22 | 5 | 37 | 42 | 46 | 40 | 69 | 1.28 | − 1.5 | 9 | 4,710 | s. | 32 | sw. | 10 | 9 | 8 | 14 | 6.2 | 0.0 | 0.0 |
| Boston | 125 | 115 | 188 | 29.92 | 30.06 | + .08 | 54.6 | − 2.0 | 86 | 28 | 62 | 36 | 5 | 48 | 31 | 50 | 46 | 74 | 5.26 | + 1.8 | 13 | 6,534 | e. | 27 | w. | 10 | 11 | 7 | 13 | 5.9 | T. | 0.0 |
| Nantucket | 12 | 14 | 90 | 30.03 | 30.04 | + .05 | 49.2 | − 3.8 | 71 | 17 | 55 | 35 | 5 | 43 | 24 | 47 | 46 | 90 | 4.15 | + 1.5 | 14 | 11,134 | ne. | 39 | e. | 22 | 9 | 6 | 16 | 6.4 | 0.0 | 0.0 |
| Block Island | 26 | 11 | 46 | 30.02 | 30.05 | + .06 | 50.9 | − 2.0 | 66 | 17 | 57 | 36 | 5 | 45 | 18 | 49 | 48 | 93 | 3.29 | − 0.5 | 13 | 11,294 | sw. | 38 | w. | 10 | 10 | 7 | 14 | 5.8 | 0.0 | 0.0 |
| Providence | 160 | 215 | 251 | 29.88 | 30.06 | + .08 | 54.5 | − 4.0 | 77 | 27 | 63 | 34 | 5 | 46 | 28 | 48 | 42 | 69 | 4.92 | + 1.5 | 14 | 8,206 | ne. | 40 | nw. | 10 | 9 | 10 | 12 | 5.8 | 0.0 | 0.0 |
| Hartford | 159 | 122 | 140 | 29.88 | 30.06 | + .08 | 56.4 | − 1.1 | 83 | 28 | 66 | 34 | 5 | 47 | 33 | 49 | 44 | 67 | 3.53 | 0.0 | 12 | 5,337 | s. | 28 | sw. | 20 | 10 | 6 | 15 | 5.7 | 0.0 | 0.0 |
| New Haven | 106 | 74 | 153 | 29.95 | 30.06 | + .07 | 56.0 | − 1.6 | 78 | 29 | 64 | 36 | 5 | 48 | 24 | 49 | 44 | 70 | 4.22 | + 0.6 | 10 | 6,898 | sw. | 36 | e. | 22 | 10 | 11 | 10 | 5.4 | 0.0 | 0.0 |
| *Middle Atlantic States.* | | | | | | | **58.6** | **− 3.1** | | | | | | | | | | **66** | **1.92** | **− 1.6** | | | | | | | | | | **5.1** | | |
| Albany | 97 | 102 | 115 | 29.94 | 30.04 | + .06 | 57.2 | − 1.7 | 85 | 27 | 67 | 33 | 5 | 48 | 30 | 50 | 43 | 61 | 0.73 | − 2.2 | 13 | 4,966 | s. | 29 | ne. | 14 | 14 | 12 | 5 | 4.1 | 0.0 | 0.0 |
| Binghamton | 871 | 10 | 84 | 29.13 | 30.07 | + .09 | 54.8 | − 2.2 | 84 | 27 | 66 | 30 | 5 | 44 | 39 | ..... | ..... | ..... | 1.51 | − 1.6 | 6 | 3,366 | nw. | 22 | w. | 4 | 11 | 6 | 14 | 5.7 | T. | 0.0 |
| New York | 314 | 414 | 454 | 29.72 | 30.06 | + .07 | 57.8 | − 1.5 | 78 | 29 | 66 | 41 | 3 | 50 | 24 | 50 | 43 | 65 | 2.88 | − 0.3 | 12 | 10,071 | s. | 51 | nw. | 1 | 9 | 12 | 10 | 5.3 | 0.0 | 0.0 |
| Harrisburg | 374 | 94 | 104 | 29.68 | 30.08 | + .10 | 59.0 | − 2.7 | 85 | 28 | 68 | 39 | 2 | 50 | 30 | 51 | 42 | 58 | 1.34 | − 2.3 | 8 | 4,495 | n. | 28 | n. | 8 | 10 | 8 | 13 | 5.2 | 0.0 | 0.0 |
| Philadelphia | 117 | 123 | 190 | 29.95 | 30.08 | + .09 | 60.4 | − 1.8 | 82 | 28 | 69 | 42 | 3 | 52 | 28 | 51 | 44 | 60 | 2.15 | − 1.0 | 9 | 7,280 | s. | 31 | n. | 1 | 13 | 6 | 12 | 4.9 | 0.0 | 0.0 |
| Reading | 325 | 81 | 98 | 29.72 | 30.07 | ..... | 59.6 | ..... | 85 | 28 | 69 | 38 | 5 | 50 | 28 | 51 | 43 | 59 | 1.39 | − 2.0 | 8 | 4,568 | n. | 28 | nw. | 1 | 12 | 6 | 13 | 5.3 | 0.0 | 0.0 |
| Scranton | 805 | 111 | 119 | 29.21 | 30.08 | + .10 | 57.2 | − 1.6 | 85 | 27 | 68 | 34 | 5 | 47 | 35 | 50 | 44 | 65 | 2.48 | − 1.0 | 8 | 4,731 | nw. | 34 | w. | 10 | 7 | 13 | 11 | 5.8 | 0.0 | 0.0 |
| Atlantic City | 52 | 37 | 48 | 30.00 | 30.06 | + .08 | 54.6 | − 2.9 | 77 | 22 | 60 | 38 | 6 | 49 | 26 | 50 | 46 | 76 | 1.61 | − 1.4 | 7 | 6,000 | ne. | 28 | ne. | 23 | 13 | 9 | 9 | 4.5 | 0.0 | 0.0 |
| Cape May | 18 | 13 | 49 | 30.07 | 30.09 | + .10 | 56.2 | − 2.4 | 78 | 22 | 62 | 41 | 6 | 50 | 23 | 51 | 47 | 75 | 1.80 | − 1.2 | 8 | 6,803 | ne. | 36 | nw. | 1 | 14 | 4 | 13 | 5.0 | 0.0 | 0.0 |
| Sandy Hook | 22 | 10 | 57 | 30.04 | 30.07 | ..... | 56.0 | ..... | 77 | 22 | 63 | 41 | 6 | 49 | 24 | 51 | 48 | 79 | 1.86 | ..... | 15 | 9,438 | se. | 38 | n. | 22 | 8 | 14 | 9 | 5.4 | 0.0 | 0.0 |
| Trenton | 190 | 159 | 183 | 29.86 | 30.06 | ..... | 58.0 | ..... | 83 | 28 | 68 | 38 | 2 | 48 | 30 | 51 | 45 | 66 | 2.66 | − 0.9 | 10 | 7,813 | s. | 37 | n. | 4 | 10 | 10 | 11 | 5.4 | 0.0 | 0.0 |
| Baltimore | 123 | 100 | 113 | 29.94 | 30.07 | + .08 | 60.8 | − 3.4 | 84 | 11 | 69 | 43 | 3 | 52 | 26 | 53 | 45 | 60 | 2.30 | − 1.3 | 9 | 5,197 | n. | 40 | n. | 21 | 12 | 7 | 12 | 5.1 | 0.0 | 0.0 |
| Washington | 112 | 62 | 85 | 29.94 | 30.06 | + .06 | 60.0 | − 4.2 | 86 | 11 | 70 | 38 | 16 | 50 | 33 | 53 | 46 | 62 | 1.42 | − 2.4 | 8 | 4,741 | s. | 38 | nw. | 1 | 13 | 5 | 13 | 5.3 | 0.0 | 0.0 |
| Lynchburg | 681 | 153 | 188 | 29.32 | 30.06 | + .06 | 61.8 | − 4.1 | 86 | 29 | 74 | 36 | 16 | 50 | 37 | 55 | 50 | 67 | 0.79 | − 3.2 | 11 | 4,811 | e. | 30 | nw. | 1 | 15 | 9 | 7 | 4.5 | 0.0 | 0.0 |
| Norfolk | 91 | 170 | 205 | 29.97 | 30.07 | + .07 | 61.4 | − 4.8 | 83 | 11 | 70 | 45 | 6 | 53 | 27 | 54 | 48 | 69 | 1.99 | − 2.1 | 8 | 8,902 | ne. | 38 | nw. | 1 | 12 | 8 | 11 | 5.2 | 0.0 | 0.0 |
| Richmond | 144 | 11 | 52 | 29.92 | 30.07 | + .08 | 60.8 | − 6.5 | 85 | 11 | 71 | 39 | 6 | 50 | 33 | 54 | 50 | 71 | 3.06 | − 0.8 | 8 | 5,370 | ne. | 30 | nw. | 1 | 12 | 2 | 17 | 6.0 | 0.0 | 0.0 |
| Wytheville | 2,304 | 49 | 56 | 27.70 | 30.05 | + .06 | 58.0 | − 3.4 | 81 | 29 | 68 | 32 | 15 | 48 | 34 | 51 | 46 | 68 | 2.53 | − 1.4 | 9 | 3,860 | e. | 20 | sw. | 11 | 12 | 13 | 6 | 4.1 | 0.0 | 0.0 |
| *South Atlantic States.* | | | | | | | **66.5** | **− 3.4** | | | | | | | | | | **71** | **2.13** | **− 1.7** | | | | | | | | | | **5.3** | | |
| Asheville | 2,255 | 70 | 84 | 27.73 | 30.05 | + .06 | 60.8 | − 1.8 | 82 | 29 | 71 | 39 | 15 | 51 | 32 | 53 | 47 | 66 | 2.06 | − 1.7 | 9 | 5,709 | se. | 26 | nw. | 1 | 8 | 18 | 5 | 5.4 | 0.0 | 0.0 |
| Charlotte | 779 | 55 | 62 | 29.21 | 30.04 | + .05 | 65.6 | − 2.8 | 86 | 12 | 76 | 44 | 15 | 55 | 28 | 57 | 50 | 61 | 1.33 | − 2.6 | 8 | 3,397 | ne. | 15 | nw. | 1 | 8 | 13 | 10 | 5.5 | 0.0 | 0.0 |
| Hatteras | 11 | 12 | 50 | 30.02 | 30.04 | + .03 | 61.1 | − 6.0 | 77 | 22 | 67 | 46 | 6 | 55 | 22 | 57 | 55 | 84 | 0.58 | − 3.6 | 6 | 11,439 | ne. | 37 | n. | 26 | 9 | 8 | 14 | 5.6 | 0.0 | 0.0 |
| Manteo | 12 | 5 | 42 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Raleigh | 376 | 103 | 110 | 29.65 | 30.05 | + .06 | 63.4 | − 4.7 | 86 | 12 | 73 | 41 | 6 | 53 | 27 | 56 | 50 | 64 | 1.03 | − 3.9 | 5 | 5,736 | ne. | 26 | nw. | 1 | 9 | 12 | 10 | 5.6 | 0.0 | 0.0 |
| Wilmington | 78 | 81 | 91 | 29.96 | 30.04 | + .03 | 64.9 | − 4.2 | 83 | 23 | 74 | 42 | 6 | 56 | 24 | 59 | 55 | 75 | 1.22 | − 2.8 | 7 | 5,663 | e. | 22 | e. | 5 | 14 | 9 | 8 | 4.6 | 0.0 | 0.0 |
| Charleston | 48 | 11 | 92 | 29.97 | 30.02 | + .01 | 68.8 | − 3.6 | 88 | 1 | 75 | 58 | 15 | 62 | 23 | 63 | 60 | 77 | 1.96 | − 1.5 | 10 | 8,637 | ne. | 35 | ne. | 16 | 9 | 8 | 14 | 5.8 | 0.0 | 0.0 |
| Columbia, S. C. | 351 | 41 | 57 | 29.66 | 30.04 | + .04 | 68.2 | − 3.6 | 88 | 23 | 78 | 48 | 7 | 58 | 29 | 59 | 53 | 62 | 1.24 | − 2.0 | 4 | 4,931 | ne. | 20 | ne. | 14 | 10 | 13 | 8 | 4.9 | 0.0 | 0.0 |
| Greenville, S. C | 1,039 | 113 | 122 | 28.94 | 30.02 | ..... | 66.2 | ..... | 87 | 23 | 76 | 47 | 15 | 57 | 26 | 57 | 51 | 63 | 1.62 | ..... | 7 | 6,171 | ne. | 27 | sw. | 12 | 8 | 16 | 7 | 5.5 | 0.0 | 0.0 |
| Augusta | 180 | 62 | 77 | 29.83 | 30.02 | + .03 | 69.6 | − 2.6 | 90 | 22 | 80 | 52 | 7 | 59 | 29 | 62 | 57 | 68 | 2.13 | − 1.1 | 8 | 4,067 | ne. | 30 | nw. | 2 | 8 | 11 | 12 | 5.7 | 0.0 | 0.0 |
| Savannah | 65 | 150 | 194 | 29.95 | 30.02 | + .02 | 70.6 | − 1.9 | 89 | 2 | 78 | 58 | 9 | 63 | 25 | 64 | 61 | 79 | 2.36 | − 0.6 | 10 | 8,793 | e. | 50 | w. | 2 | 8 | 13 | 10 | 5.3 | 0.0 | 0.0 |
| Jacksonville | 43 | 209 | 245 | 29.94 | 29.99 | − .01 | 71.9 | − 2.3 | 87 | 13 | 78 | 61 | 9 | 66 | 22 | 66 | 64 | 81 | 7.41 | + 3.2 | 12 | 9,338 | ne. | 34 | ne. | 16 | 15 | 9 | 7 | 4.3 | 0.0 | 0.0 |
| *Florida Peninsula.* | | | | | | | **77.1** | **− 0.9** | | | | | | | | | | **74** | **5.00** | **+ 0.8** | | | | | | | | | | **4.1** | | |
| Key West | 22 | 10 | 64 | 29.91 | 29.93 | − .04 | 79.0 | 0.0 | 87 | 2 | 84 | 69 | 18 | 74 | 15 | 72 | 69 | 73 | 3.18 | − 0.2 | 7 | 7,031 | nw. | 30 | e. | 16 | 19 | 9 | 3 | 3.1 | 00 | 00 |
| Miami | 25 | 71 | 79 | 29.92 | 29.95 | ..... | 76.2 | − 2.4 | 87 | 30 | 82 | 64 | 23 | 70 | 21 | 70 | 68 | 75 | 10.33 | + 4.0 | 14 | 6,760 | e. | 36 | ne. | 17 | 9 | 15 | 7 | 5.2 | 00 | 00 |
| Sand Key | 23 | 39 | 72 | 29.88 | 29.91 | − .06 | 77.5 | ..... | 85 | 14 | 80 | 69 | 14 | 75 | 16 | 72 | 69 | 74 | 2.26 | ..... | 6 | 8,149 | e. | 38 | e. | 16 | 23 | 6 | 2 | 2.8 | 00 | 00 |
| Tampa | 35 | 79 | 92 | 29.92 | 29.96 | − .03 | 76.0 | − 0.4 | 89 | 12 | 84 | 62 | 10 | 68 | 23 | 68 | 65 | 73 | 1.49 | − 1.4 | 8 | 5,439 | ne. | 27 | e. | 17 | 7 | 18 | 6 | 5.3 | 00 | 00 |
| *East Gulf States.* | | | | | | | **71.9** | **− 0.3** | | | | | | | | | | **76** | **4.72** | **+ 1.2** | | | | | | | | | | **6.5** | | |
| Atlanta | 1,174 | 190 | 216 | 28.80 | 30.03 | + .04 | 67.1 | − 2.4 | 86 | 24 | 75 | 52 | 14 | 59 | 25 | 60 | 56 | 71 | 4.58 | + 1.5 | 11 | 6,838 | se. | 58 | nw. | 2 | 7 | 7 | 17 | 6.9 | 00 | 00 |
| Leesburg | 279 | 10 | 55 | 29.72 | 30.02 | ..... | 71.0 | ..... | 92 | 24 | 80 | 54 | 10 | 62 | 28 | 64 | 61 | 75 | 5.08 | ..... | 12 | 5,038 | e. | 35 | nw. | 13 | 3 | 5 | 23 | 7.8 | 00 | 00 |
| Macon | 370 | 78 | 87 | 29.62 | 30.01 | + .02 | 69.8 | − 1.3 | 90 | 23 | 79 | 52 | 10 | 60 | 28 | 62 | 58 | 70 | 4.96 | + 2.1 | 9 | 4,284 | e. | 26 | nw. | 2 | 5 | 9 | 17 | 6.8 | 00 | 00 |
| Thomasville | 273 | 49 | 58 | 29.69 | 29.98 | − .01 | 72.8 | − 1.2 | 94 | 24 | 82 | 58 | 17 | 64 | 26 | 65 | 62 | 74 | 3.36 | − 0.6 | 8 | 3,472 | ne. | 21 | w. | 3 | 3 | 12 | 16 | 7.2 | 00 | 00 |
| Pensacola | 56 | 149 | 185 | 29.92 | 29.98 | − .01 | 72.9 | − 1.9 | 88 | 24 | 79 | 61 | 19 | 67 | 23 | 68 | 66 | 82 | 4.81 | + 2.3 | 11 | 9,646 | se. | 64 | n. | 25 | 6 | 10 | 15 | 6.5 | 00 | 00 |
| Anniston | 741 | 9 | 57 | 29.24 | 30.03 | ..... | 68.2 | − 0.2 | 89 | 24 | 78 | 45 | 9 | 58 | 35 | ..... | ..... | ..... | 6.61 | + 3.5 | 12 | 3,747 | se. | 27 | nw. | 13 | 8 | 14 | 9 | 5.6 | 00 | 00 |
| Birmingham | 700 | 11 | 48 | 29.26 | 30.02 | + .04 | 69.8 | − 1.8 | 91 | 23 | 78 | 51 | 9 | 61 | 28 | 63 | 59 | 75 | 7.94 | + 4.8 | 13 | 4,204 | se. | 38 | se. | 30 | 6 | 14 | 11 | 6.1 | 00 | 00 |
| Mobile | 57 | 125 | 161 | 29.91 | 29.97 | − .02 | 75.1 | + 1.5 | 95 | 23 | 83 | 60 | 9 | 67 | 25 | 69 | 67 | 81 | 3.70 | − 0.3 | 11 | 6,491 | sw. | 36 | ne. | 4 | 6 | 17 | 8 | 5.9 | 00 | 00 |
| Montgomery | 223 | 100 | 112 | 29.76 | 30.00 | + .01 | 71.6 | − 1.5 | 91 | 24 | 80 | 56 | 10 | 64 | 25 | 65 | 61 | 73 | 4.14 | + 0.3 | 15 | 4,435 | e. | 30 | n. | 25 | 5 | 14 | 12 | 6.2 | 00 | 00 |
| Corinth | 469 | 6 | .... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Meridian | 375 | 85 | 93 | 29.59 | 29.98 | .00 | 72.1 | + 1.0 | 90 | 23 | 81 | 53 | 9 | 64 | 28 | 66 | 63 | 79 | 3.41 | − 0.5 | 16 | 3,605 | ne. | 24 | nw. | 4 | 2 | 19 | 10 | 6.7 | 00 | 00 |
| Vicksburg | 247 | 65 | 74 | 29.70 | 29.98 | + .01 | 74.0 | + 1.1 | 90 | 23 | 82 | 56 | 15 | 66 | 21 | 68 | 65 | 81 | 4.37 | + 0.1 | 9 | 4,534 | se. | 31 | se. | 28 | 6 | 12 | 13 | 6.0 | 00 | 00 |
| New Orleans | 53 | 76 | 84 | 29.90 | 29.96 | − .01 | 78.0 | + 3.5 | 91 | 23 | 85 | 64 | 15 | 71 | 20 | 71 | 69 | 80 | 4.08 | + 0.2 | 9 | 4,408 | se. | 23 | sw. | 16 | 4 | 15 | 12 | 6.5 | 00 | 00 |
| *West Gulf States.* | | | | | | | **74.3** | **+ 1.4** | | | | | | | | | | **77** | **4.84** | **+ 0.8** | | | | | | | | | | **5.7** | | |
| Shreveport | 249 | 77 | 93 | 29.67 | 29.94 | − .01 | 75.2 | + 2.0 | 93 | 23 | 84 | 55 | 15 | 66 | 25 | 68 | 64 | 73 | 5.18 | + 1.0 | 10 | 5,074 | se. | 48 | w. | 5 | 15 | 10 | 6 | 4.5 | 00 | 00 |
| Bentonville | 1,303 | 11 | 44 | 28.59 | 29.94 | − .01 | 67.4 | + 1.0 | 87 | 26 | 77 | 43 | 14 | 58 | 30 | ..... | ..... | ..... | 5.84 | + 1.2 | 16 | 3,684 | s. | 20 | n. | 6 | 7 | 10 | 14 | 6.7 | 00 | 00 |
| Fort Smith | 457 | 79 | 94 | 29.45 | 29.92 | − .01 | 72.2 | + 2.5 | 91 | 31 | 81 | 48 | 15 | 63 | 29 | 64 | 61 | 72 | 2.12 | − 2.8 | 8 | 5,515 | e. | 34 | e. | 15 | 9 | 11 | 11 | 5.6 | 00 | 00 |
| Little Rock | 357 | 139 | 147 | 29.58 | 29.95 | 00 | 71.0 | + 0.6 | 89 | 23 | 79 | 50 | 16 | 63 | 24 | 65 | 62 | 77 | 8.18 | + 3.1 | 15 | 5,685 | e. | 47 | nw. | 4 | 10 | 12 | 9 | 5.5 | 00 | 00 |
| Brownsville | 57 | 4 | 26 | ..... | ..... | ..... | 80.8 | ..... | 96 | 29 | 90 | 65 | 18 | 71 | 27 | ..... | ..... | ..... | 2.90 | ..... | 4 | ..... | se. | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 00 | 00 |
| Corpus Christi | 20 | 69 | 77 | 29.88 | 29.90 | 00 | 77.6 | + 1.1 | 89 | 27 | 82 | 64 | 17 | 73 | 19 | 72 | 71 | 83 | 4.06 | + 1.3 | 7 | 11,215 | se. | 48 | n. | 7 | 9 | 11 | 11 | 5.7 | 00 | 00 |
| Dallas | 512 | 109 | 117 | 29.37 | 29.91 | ..... | 73.8 | ..... | 95 | 3 | 82 | 53 | 15 | 65 | 30 | ..... | ..... | ..... | 12.92 | ..... | 12 | 6,781 | s. | 52 | nw. | 5 | 6 | 14 | 11 | 5.8 | 00 | 00 |
| Fort Worth | 670 | 106 | 114 | 29.18 | 29.88 | − .03 | 73.4 | + 0.2 | 97 | 3 | 83 | 50 | 16 | 64 | 37 | 66 | 63 | 76 | 8.66 | + 4.5 | 10 | 7,628 | s. | 50 | nw. | 4 | 9 | 11 | 11 | 5.5 | 00 | 00 |
| Galveston | 54 | 106 | 114 | 29.89 | 29.95 | + .01 | 76.6 | + 1.2 | 89 | 26 | 81 | 63 | 16 | 72 | 16 | 71 | 70 | 82 | 3.86 | + 0.6 | 6 | 8,413 | se. | 32 | e. | 16 | 16 | 11 | 4 | 4.4 | 00 | 00 |
| Groesbeck | 461 | 11 | 56 | 29.41 | 29.88 | ..... | 75.0 | ..... | 93 | 26 | 85 | 54 | 18 | 65 | 29 | 68 | 65 | 77 | 2.57 | ..... | 9 | 8,045 | s. | 51 | s. | 5 | 6 | 17 | 8 | 5.9 | 00 | 00 |
| Houston | 138 | 111 | 121 | 29.77 | 29.91 | ..... | 77.4 | + 1.9 | 94 | 26 | 86 | 62 | 16 | 69 | 25 | ..... | ..... | ..... | 4.79 | ..... | 8 | 6,561 | se. | 39 | e. | 16 | 8 | 16 | 7 | 5.2 | 00 | 00 |
| Palestine | 510 | 64 | 72 | 29.40 | 29.92 | − .01 | 74.6 | + 2.1 | 92 | 26 | 84 | 55 | 15 | 65 | 27 | 68 | 65 | 76 | 2.71 | − 2.2 | 10 | 5,446 | s. | 29 | nw. | 3 | 5 | 11 | 15 | 6.3 | 00 | 00 |
| Port Arthur | 34 | 58 | 66 | 29.88 | 29.92 | ..... | 76.6 | ..... | 90 | 26 | 83 | 63 | 16 | 70 | 20 | 70 | 68 | 81 | 5.63 | ..... | 8 | 7,045 | s. | 48 | nw. | 16 | 12 | 12 | 7 | 5.5 | 00 | 00 |
| San Antonio | 701 | 119 | 132 | 29.17 | 29.88 | − .02 | 76.8 | + 2.0 | 92 | 3 | 86 | 59 | 18 | 67 | 26 | 69 | 66 | 76 | 2.42 | − 0.5 | 7 | 6,179 | se. | 42 | se. | 2 | 3 | 16 | 12 | 6.6 | 00 | 00 |
| Taylor | 582 | 55 | 63 | 29.32 | 29.93 | + .02 | 75.5 | + 1.2 | 92 | 26 | 85 | 56 | 16 | 66 | 25 | ..... | ..... | ..... | 5.37 | + 1.4 | 8 | 6,476 | s. | 44 | nw. | 7 | 3 | 16 | 12 | 6.7 | 00 | 00 |

TABLE I.—*Climatological data for Weather Bureau Stations, May, 1920*—Continued.

| Districts and stations. | Elevation of instruments. | | | Pressure. | | | Temperature of the air. | | | | | | | | | | | | Mean wet thermometer. | Mean temperature of the dew-point. | Mean relative humidity. | Precipitation. | | | Wind. | | | | | | Clear days. | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 24 hours. | Departure from normal. | Mean max.+mean min.÷2. | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | | | Total. | Departure from normal. | Days with 0.01 inch or more. | Total movement. | Prevailing direction. | Maximum velocity. Miles per hour. | Maximum velocity. Direction. | Maximum velocity. Date. | | | | | | | |
| *Ohio Valley and Tennessee.* | *Ft.* | *Ft.* | *Ft.* | *In.* | *In.* | *In.* | ° *F.* | ° *F.* | ° *F.* | | ° *F.* | ° *F.* | | ° *F.* | ° *F.* | ° *F.* | ° *F.* | ° *F.* | % | *In.* | *In.* | | *Miles.* | | | | | | | | | *0–10* | *In.* | *In.* |
| | | | | | | | **63.0** | **— 2.0** | | | | | | | | | | | **64** | **3.38** | **— 0.3** | | | | | | | | | | **5.8** | | |
| Chattanooga | 762 | 189 | 213 | 29.24 | 30.04 | + .05 | 67.0 | — 1.6 | 88 | 23 | 76 | 48 | 15 | 58 | 28 | 59 | 54 | 68 | 4.59 | + 1.0 | 11 | 5,179 | s. | 28 | se. | 17 | 6 | 10 | 15 | 6.4 | 00 | 00 |
| Knoxville | 996 | 102 | 111 | 28.98 | 30.02 | + .03 | 66.0 | — 0.5 | 88 | 23 | 76 | 44 | 15 | 56 | 29 | 57 | 51 | 62 | 2.31 | — 1.4 | 8 | 3,865 | n. | 30 | sw. | 12 | 5 | 13 | 13 | 6.6 | 00 | 00 |
| Memphis | 399 | 76 | 97 | 29.59 | 30.01 | + .05 | 70.5 | — 0.2 | 88 | 23 | 78 | 51 | 15 | 63 | 25 | 64 | 62 | 77 | 8.12 | + 3.8 | 13 | 5,104 | ne. | 52 | nw. | 3 | 9 | 8 | 14 | 6.5 | 00 | 00 |
| Nashville | 546 | 168 | 191 | 29.45 | 30.03 | + .05 | 67.0 | — 1.8 | 89 | 23 | 76 | 46 | 15 | 58 | 27 | 59 | 54 | 68 | 3.18 | — 0.3 | 10 | 6,366 | ne. | 39 | sw. | 30 | 6 | 12 | 13 | 6.4 | 00 | 00 |
| Lexington | 989 | 193 | 230 | 28.99 | 30.05 | + .06 | 62.4 | — 1.9 | 87 | 30 | 71 | 38 | 14 | 54 | 31 | | | | 2.51 | — 1.0 | 8 | 9,014 | ne. | 40 | sw. | 12 | 10 | 10 | 11 | 5.5 | 00 | 00 |
| Louisville | 525 | 219 | 255 | 29.48 | 30.06 | + .08 | 64.7 | — 2.0 | 89 | 23 | 74 | 42 | 15 | 56 | 30 | 56 | 51 | 67 | 2.53 | — 1.1 | 11 | 7,958 | n. | 44 | sw. | 30 | 12 | 8 | 11 | 4.8 | 00 | 00 |
| Evansville | 431 | 139 | 175 | 29.57 | 30.04 | + .07 | 65.6 | — 1.5 | 88 | 23 | 75 | 41 | 14 | 56 | 24 | 58 | 52 | 68 | 5.18 | + 1.8 | 14 | 7,978 | ne. | 37 | sw. | 12 | 7 | 12 | 12 | 5.9 | 00 | 00 |
| Indianapolis | 822 | 194 | 230 | 29.18 | 30.06 | + .09 | 61.0 | — 2.3 | 85 | 30 | 70 | 36 | 15 | 52 | 31 | 53 | 46 | 61 | 5.04 | + 1.1 | 10 | 8,778 | ne. | 36 | sw. | 30 | 7 | 15 | 9 | 5.5 | 00 | 00 |
| Royal Center | 736 | 11 | 55 | 29.27 | 30.07 | ..... | 57.7 | ..... | 81 | 23 | 68 | 32 | 14 | 47 | 33 | 51 | 46 | 67 | 2.45 | ..... | 8 | 7,544 | e. | 40 | ne. | 12 | 7 | 16 | 8 | 5.8 | 00 | 00 |
| Terre Haute | 575 | 96 | 129 | 29.41 | 30.02 | ..... | 62.6 | ..... | 86 | 23 | 72 | 36 | 14 | 53 | 29 | 55 | 49 | 65 | 4.90 | ..... | 11 | 6,943 | ne. | 31 | nw. | 18 | 5 | 16 | 10 | 6.0 | 00 | 00 |
| Cincinnati | 628 | 11 | 51 | 29.38 | 30.06 | + .07 | 60.8 | — 2.3 | 85 | 23 | 71 | 36 | 14 | 51 | 29 | 54 | 47 | 62 | 4.36 | + 0.8 | 8 | 5,479 | ne. | 36 | sw. | 11 | 11 | 9 | 11 | 5.3 | 00 | 00 |
| Columbus | 824 | 179 | 222 | 29.20 | 30.07 | + .09 | 59.4 | — 2.9 | 84 | 30 | 69 | 34 | 3 | 50 | 30 | 52 | 45 | 61 | 2.00 | — 1.7 | 8 | 8,052 | e. | 34 | n. | 13 | 10 | 12 | 9 | 5.4 | 00 | 00 |
| Dayton | 899 | 181 | 216 | 29.08 | 30.03 | ..... | 60.6 | — 2.3 | 86 | 30 | 71 | 36 | 14 | 51 | 31 | 52 | 45 | 60 | 2.71 | — 1.2 | 9 | 7,668 | ne. | 40 | n. | 23 | 14 | 9 | 8 | 4.6 | 00 | 00 |
| Elkins | 1,947 | 59 | 67 | 28.02 | 30.07 | + .07 | 56.0 | — 3.1 | 84 | 31 | 68 | 29 | 15 | 44 | 39 | 49 | 43 | 66 | 2.19 | — 1.8 | 7 | 3,548 | nw. | 28 | nw. | 1 | 7 | 12 | 12 | 6.1 | 00 | 00 |
| Parkersburg | 638 | 77 | 84 | 29.42 | 30.08 | + .09 | 61.4 | — 1.9 | 88 | 31 | 72 | 34 | 15 | 51 | 33 | 53 | 46 | 61 | 1.64 | — 1.8 | 7 | 3,465 | nw. | 22 | sw. | 19 | 10 | 13 | 8 | 5.2 | 00 | 00 |
| Pittsburgh | 842 | 353 | 410 | 29.16 | 30.07 | + .08 | 59.6 | — 3.0 | 87 | 31 | 70 | 35 | 15 | 50 | 29 | 50 | 42 | 54 | 1.03 | — 2.3 | 7 | 7,779 | nw. | 33 | nw. | 1 | 13 | 6 | 12 | 5.5 | 00 | 00 |
| *Lower Lake Region.* | | | | | | | **55.4** | **— 2.0** | | | | | | | | | | | **64** | **0.97** | **— 2.2** | | | | | | | | | | **4.8** | | |
| Buffalo | 767 | 247 | 280 | 29.25 | 30.09 | + .12 | 53.2 | — 1.3 | 80 | 30 | 61 | 31 | 2 | 45 | 28 | 47 | 41 | 66 | 1.10 | — 2.0 | 7 | 7,856 | w. | 37 | sw. | 18 | 12 | 6 | 13 | 5.4 | 0.0 | 0.0 |
| Canton | 448 | 10 | 61 | 29.56 | 30.04 | ..... | 55.0 | — 1.2 | 82 | 31 | 65 | 33 | 5 | 45 | 36 | ..... | ..... | ..... | 1.41 | — 1.4 | 10 | 5,769 | w. | 35 | sw. | 9 | 14 | 13 | 4 | 4.0 | 0.4 | 0.0 |
| Oswego | 335 | 76 | 91 | 29.69 | 30.06 | + .09 | 51.8 | — 2.7 | 84 | 31 | 60 | 34 | 5 | 44 | 29 | 47 | 41 | 68 | 0.18 | — 2.7 | 3 | 5,739 | w. | 23 | nw. | 22 | 12 | 8 | 11 | 4.6 | T. | 0.0 |
| Rochester | 523 | 86 | 102 | 29.51 | 30.09 | + .11 | 55.8 | — 0.9 | 86 | 31 | 65 | 33 | 2 | 46 | 30 | 48 | 41 | 61 | 0.78 | — 2.2 | 7 | 5,044 | nw. | 24 | nw. | 1 | 11 | 10 | 10 | 4.7 | 0.0 | 0.0 |
| Syracuse | 597 | 97 | 113 | 29.44 | 30.08 | + .10 | 55.0 | — 2.3 | 83 | 31 | 64 | 34 | 5 | 46 | 33 | ..... | ..... | ..... | 0.19 | — 3.2 | 5 | 6,758 | nw. | 33 | sw. | 20 | 14 | 7 | 10 | 4.8 | T. | 0.0 |
| Erie | 714 | 130 | 166 | 29.30 | 30.08 | + .10 | 55.2 | — 2.1 | 81 | 23 | 63 | 34 | 15 | 48 | 29 | 49 | 42 | 62 | 1.04 | — 2.4 | 6 | 7,327 | ne. | 37 | w. | 9 | 17 | 9 | 5 | 4.1 | T. | 0.0 |
| Cleveland | 762 | 190 | 201 | 29.26 | 30.10 | + .12 | 55.6 | — 2.9 | 81 | 31 | 62 | 38 | 15 | 49 | 27 | 49 | 43 | 65 | 1.12 | — 2.1 | 7 | 8,052 | ne. | 35 | ne. | 13 | 13 | 9 | 9 | 4.9 | 0.0 | 0.0 |
| Sandusky | 629 | 62 | 103 | 29.41 | 30.10 | + .12 | 56.3 | — 2.9 | 83 | 31 | 63 | 39 | 2 | 49 | 26 | ..... | ..... | ..... | 1.85 | — 1.4 | 8 | 7,521 | ne. | 38 | ne. | 13 | 10 | 12 | 9 | 5.0 | 0.0 | 0.0 |
| Toledo | 628 | 208 | 243 | 29.41 | 30.09 | + .12 | 57.0 | — 2.7 | 85 | 27 | 66 | 33 | 3 | 48 | 28 | 50 | 45 | 67 | 1.59 | — 1.7 | 6 | 9,039 | ne. | 45 | sw. | 31 | 16 | 7 | 8 | 4.5 | 0.0 | 0.0 |
| Fort Wayne | 856 | 113 | 124 | 29.16 | 30.09 | ..... | 58.4 | — 1.8 | 83 | 27 | 68 | 35 | 3 | 49 | 30 | 50 | 42 | 59 | 2.01 | ..... | 7 | 6,396 | ne. | 30 | ne. | 12 | 9 | 12 | 10 | 5.4 | 0.0 | 0.0 |
| Detroit | 730 | 218 | 245 | 29.31 | 30.10 | + .13 | 56.4 | — 1.5 | 84 | 27 | 66 | 34 | 2 | 47 | 31 | 48 | 41 | 60 | 0.43 | — 2.8 | 7 | 7,368 | ne. | 36 | sw. | 31 | 10 | 12 | 9 | 5.4 | 0.0 | 0.0 |
| *Upper Lake Region.* | | | | | | | **52.8** | **+ 0.1** | | | | | | | | | | | **66** | **1.68** | **— 1.8** | | | | | | | | | | **4.3** | | |
| Alpena | 609 | 13 | 92 | 29.44 | 30.11 | + .14 | 49.6 | + 0.1 | 75 | 27 | 59 | 28 | 2 | 40 | 30 | 45 | 40 | 70 | 0.52 | — 2.8 | 5 | 7,537 | se. | 33 | nw. | 21 | 10 | 13 | 8 | 4.7 | 0.0 | 0.0 |
| Escanaba | 612 | 54 | 60 | 29.44 | 30.11 | + .14 | 49.8 | — 0.2 | 72 | 19 | 58 | 27 | 2 | 42 | 27 | 45 | 39 | 68 | 0.87 | — 2.6 | 7 | 6,446 | s. | 35 | ne. | 12 | 21 | 8 | 2 | 2.3 | 0.0 | 0.0 |
| Grand Haven | 632 | 54 | 89 | 29.40 | 30.08 | + .12 | 52.8 | — 2.0 | 78 | 30 | 62 | 31 | 3 | 44 | 27 | 48 | 41 | 65 | 1.92 | — 1.4 | 7 | 7,040 | w. | 33 | nw. | 23 | 12 | 13 | 6 | 4.7 | 0.0 | 0.0 |
| Grand Rapids | 707 | 70 | 87 | 29.32 | 30.10 | + .13 | 57.1 | — 1.9 | 82 | 26 | 68 | 32 | 14 | 46 | 33 | 49 | 41 | 58 | 1.92 | — 1.4 | 8 | 4,018 | se. | 19 | nw. | 21 | 13 | 13 | 5 | 4.4 | 0.0 | 0.0 |
| Houghton | 684 | 62 | 99 | 29.38 | 30.11 | + .14 | 51.0 | + 1.3 | 80 | 30 | 62 | 28 | 3 | 40 | 35 | ..... | ..... | ..... | 1.42 | — 1.9 | 7 | 6,538 | e. | 39 | w. | 27 | 10 | 10 | 6 | 4.1 | 0.0 | 0.0 |
| Lansing | 878 | 11 | 62 | 29.15 | 30.09 | ..... | 55.1 | — 2.8 | 82 | 26 | 68 | 28 | 3 | 42 | 37 | 49 | 42 | 64 | 1.43 | — 2.2 | 8 | 4,186 | ne. | 23 | **w.** | 9 | 7 | 14 | 10 | 5.5 | 0.0 | 0.0 |
| Ludington | 637 | 60 | 66 | 29.40 | 30.10 | ..... | 50.4 | ..... | 73 | 22 | 59 | 29 | 3 | 42 | 25 | 47 | 43 | 75 | 2.51 | ..... | 9 | 6,531 | s. | 35 | sw. | 22 | 19 | 7 | 5 | 3.4 | 0.0 | 0.0 |
| Marquette | 734 | 77 | 111 | 29.32 | 30.13 | + .16 | 50.4 | + 1.4 | 85 | 31 | 59 | 28 | 3 | 42 | 37 | 44 | 38 | 65 | 0.74 | — 2.6 | 6 | 6,248 | nw. | 44 | s. | 22 | 11 | 12 | 8 | 4.8 | T. | 0.0 |
| Port Huron | 638 | 70 | 120 | 29.40 | 30.10 | + .13 | 57.4 | + 3.7 | 83 | 27 | 60 | 30 | 2 | 42 | 34 | 46 | 41 | 72 | 0.89 | — 2.4 | 6 | 7,394 | ne. | 37 | w. | 9 | 14 | 11 | 6 | 4.1 | 0.0 | 0.0 |
| Saginaw | 641 | 69 | 77 | 29.40 | 30.10 | ..... | 54.7 | ..... | 82 | 31 | 65 | 31 | 2 | 44 | 32 | 48 | 41 | 62 | 1.44 | — 2.7 | 6 | 5,636 | ne. | 28 | s. | 31 | 12 | 9 | 10 | 5.0 | 0.0 | 0.0 |
| Sault Sainte Marie | 614 | 11 | 52 | 29.42 | 30.12 | + .17 | 48.6 | + 0.9 | 85 | 31 | 59 | 28 | 14 | 38 | 38 | 44 | 39 | 70 | 1.37 | — 1.9 | 8 | 6,126 | nw. | 37 | nw. | 27 | 17 | 10 | 4 | 3.8 | T. | 0.0 |
| Chicago | 823 | 140 | 310 | 29.20 | 30.09 | + .13 | 55.4 | — 1.1 | 82 | 31 | 62 | 28 | 2 | 49 | 30 | 48 | 42 | 65 | 1.81 | — 1.6 | 6 | 8,414 | ne. | 31 | s. | 17 | 13 | 13 | 5 | 4.6 | 0.0 | 0.0 |
| Green Bay | 617 | 109 | 144 | 29.42 | 30.08 | + .13 | 54.6 | + 0.1 | 83 | 31 | 65 | 30 | 3 | 44 | 31 | 47 | 40 | 62 | 1.43 | — 2.1 | 6 | 7,479 | ne. | 41 | n. | 9 | 12 | 15 | 4 | 4.8 | 0.0 | 0.0 |
| Milwaukee | 681 | 125 | 139 | 29.35 | 30.09 | + .13 | 53.1 | — 0.5 | 78 | 21 | 61 | 35 | 14 | 45 | 32 | 46 | 39 | 63 | 2.61 | — 0.8 | 9 | 6,687 | ne. | 37 | sw. | 22 | 13 | 11 | 7 | 4.6 | 0.0 | 0.0 |
| Duluth | 1,133 | 11 | 47 | 28.86 | 30.09 | + .13 | 51.0 | + 2.4 | 78 | 25 | 61 | 31 | 1 | 41 | 37 | 44 | 36 | 60 | 4.67 | + 1.2 | 8 | 8,249 | ne. | 49 | nw. | 27 | 15 | 8 | 8 | 4.2 | 0.0 | 0.0 |
| *North Dakota.* | | | | | | | **54.9** | **+ 0.7** | | | | | | | | | | | **60** | **1.77** | **— 0.7** | | | | | | | | | | **5.3** | | |
| Moorhead | 940 | 8 | 57 | 29.04 | 30.06 | + .12 | 55.6 | + 0.8 | 83 | 25 | 69 | 28 | 1 | 42 | 39 | 49 | 42 | 65 | 2.53 | — 0.4 | 11 | 6,010 | se. | 30 | nw. | 22 | 17 | 8 | 6 | 3.6 | 0.0 | 0.0 |
| Bismarck | 1,674 | 8 | 57 | 28.26 | 30.04 | + .12 | 54.8 | — 0.4 | 82 | 21 | 66 | 35 | 13 | 43 | 41 | 46 | 38 | 57 | 1.27 | — 1.2 | 7 | 9,166 | e. | 38 | s. | 15 | 8 | 8 | 15 | 6.3 | 0.0 | 0.0 |
| Devils Lake | 1,482 | 11 | 44 | 28.44 | 30.01 | + .07 | 54.4 | + 1.7 | 80 | 29 | 67 | 27 | 1 | 42 | 40 | 46 | 37 | 56 | 1.24 | — 1.0 | 8 | 8,730 | se. | 42 | w. | 26 | 11 | 10 | 10 | 5.3 | 0.0 | 0.0 |
| Ellendale | 1,457 | 10 | 56 | 28.47 | 30.04 | ..... | 53.8 | ..... | 84 | 25 | 66 | 32 | 14 | 42 | 44 | 48 | 41 | 64 | 2.54 | ..... | 11 | 11,889 | s. | 49 | e. | 11 | 6 | 11 | 14 | 6.4 | 0.0 | 0.0 |
| Grand Forks | 815 | 12 | 89 | ..... | ..... | ..... | 54.6 | ..... | 80 | 29 | 69 | 22 | 1 | 41 | 40 | 50 | ..... | ..... | 2.01 | ..... | 8 | ..... | se. | 35 | nw. | 26 | 15 | 9 | 7 | ..... | 0.0 | 0.0 |
| Williston | 1,878 | 41 | 48 | 27.98 | 29.96 | + .03 | 54.9 | + 0.6 | 84 | 21 | 66 | 33 | 2 | 44 | 40 | 46 | 36 | 56 | 2.03 | — 0.2 | 9 | 8,483 | se. | 42 | e. | 11 | 8 | 17 | 6 | 5.1 | T. | 0.0 |
| *Upper Mississippi Valley.* | | | | | | | **60.9** | **— 1.1** | | | | | | | | | | | **65** | **3.53** | **— 0.7** | | | | | | | | | | **5.6** | | |
| Minneapolis | 918 | 102 | 208 | 29.04 | 30.02 | ..... | 59.3 | ..... | 84 | 25 | 70 | 36 | 13 | 49 | 28 | ..... | ..... | ..... | 2.67 | — 1.2 | 7 | 7,583 | se. | 43 | e. | 10 | 13 | 6 | 12 | 5.2 | 0.0 | 0.0 |
| St. Paul | 837 | 236 | 261 | 29.17 | 30.07 | + .13 | 59.0 | + 0.8 | 82 | 25 | 69 | 37 | 3 | 49 | 26 | ..... | ..... | ..... | 1.97 | — 1.6 | 7 | 7,832 | se. | 43 | s. | 22 | 13 | 11 | 7 | 4.4 | 0.0 | 0.0 |
| La Crosse | 714 | 11 | 48 | 29.30 | 30.08 | + .14 | 58.4 | — 1.1 | 85 | 31 | 70 | 34 | 14 | 46 | 33 | ..... | ..... | ..... | 1.86 | — 1.9 | 8 | 3,266 | s. | 19 | se. | 22 | 14 | 8 | 9 | 5.1 | 0.0 | 0.0 |
| Madison | 974 | 70 | 78 | 29.05 | 30.10 | + .11 | 56.6 | — 1.0 | 82 | 31 | 66 | 33 | 3 | 47 | 29 | 48 | 41 | 61 | 2.51 | — 1.1 | 9 | 6,326 | se. | 48 | se. | 22 | 10 | 10 | 11 | 5.8 | 0.0 | 0.0 |
| Wausau | 1,247 | 4 | ..... | 28.76 | 30.09 | ..... | 54.6 | ..... | 84 | 31 | 67 | 28 | 3 | 42 | 33 | ..... | ..... | ..... | 2.39 | ..... | 8 | ..... | se. | ..... | ..... | ..... | 14 | 6 | 11 | ..... | 0.0 | 0.0 |
| Charles City | 1,015 | 10 | 49 | 28.99 | 30.06 | + .12 | 57.9 | — 1.6 | 84 | 31 | 69 | 34 | 14 | 46 | 34 | 51 | 44 | 64 | 4.54 | — 0.4 | 10 | 4,512 | se. | 32 | sw. | 22 | 10 | 15 | 6 | 5.1 | 0.0 | 0.0 |
| Davenport | 606 | 71 | 79 | 29.40 | 30.06 | + .11 | 60.5 | — 1.0 | 84 | 26 | 70 | 35 | 14 | 50 | 32 | 52 | 46 | 62 | 2.83 | — 1.4 | 8 | 6,007 | e. | 46 | ne. | 12 | 10 | 12 | 9 | 5.4 | 0.0 | 0.0 |
| Des Moines | 861 | 84 | 97 | 29.12 | 30.02 | + .09 | 61.2 | — 0.4 | 87 | 22 | 70 | 40 | 3 | 52 | 30 | 53 | 47 | 67 | 3.14 | — 1.4 | 6 | 5,797 | e. | 33 | sw. | 22 | 5 | 7 | 19 | 7.2 | 0.0 | 0.0 |
| Dubuque | 698 | 81 | 96 | 29.33 | 30.08 | + .13 | 58.8 | — 2.0 | 82 | 31 | 69 | 35 | 3 | 49 | 31 | 51 | 43 | 59 | 2.86 | — 1.5 | 7 | 4,349 | e. | 20 | s. | 22 | 9 | 11 | 11 | 5.7 | 0.0 | 0.0 |
| Keokuk | 614 | 64 | 78 | 29.37 | 30.04 | + .10 | 61.8 | — 1.4 | 86 | 22 | 70 | 39 | 3 | 53 | 27 | 55 | 49 | 65 | 3.36 | — 0.9 | 7 | 5,187 | ne. | 24 | ne. | 12 | 6 | 11 | 14 | 6.5 | 0.0 | 0.0 |
| Cairo | 356 | 87 | 93 | 29.62 | 29.99 | + .03 | 67.2 | — 0.3 | 90 | 23 | 75 | 43 | 14 | 59 | 23 | 61 | 57 | 77 | 5.02 | + 1.2 | 13 | 6,638 | ne. | 33 | sw. | 31 | 4 | 10 | 17 | 6.8 | 0.0 | 0.0 |
| Peoria | 609 | 11 | 45 | 29.39 | 30.06 | + .10 | 60.8 | — 0.9 | 85 | 26 | 72 | 34 | 14 | 50 | 36 | 54 | 48 | 67 | 3.03 | — 1.2 | 9 | 4,854 | e. | 23 | ne. | 12 | 11 | 12 | 8 | 4.5 | 0.0 | 0.0 |
| Springfield | 644 | 10 | 91 | 29.35 | 30.02 | + .07 | 62.2 | — 1.3 | 84 | 26 | 72 | 35 | 14 | 53 | 26 | 55 | 50 | 69 | 6.89 | + 2.4 | 10 | 6,043 | ne. | 33 | se. | 2 | 9 | 11 | 11 | 5.7 | 0.0 | 0.0 |
| Hannibal | 534 | 74 | 109 | 29.45 | 30.02 | + .08 | 62.1 | — 2.3 | 87 | 22 | 71 | 38 | 14 | 53 | 29 | ..... | ..... | ..... | 3.80 | — 1.2 | 11 | 6,632 | ne. | 36 | n. | 12 | 6 | 11 | 14 | 6.3 | 0.0 | 0.0 |
| St. Louis | 567 | 265 | 303 | 29.40 | 30.01 | + .06 | 64.8 | — 1.7 | 88 | 22 | 73 | 37 | 14 | 57 | 28 | 57 | 51 | 66 | 5.00 | + 0.8 | 14 | 8,174 | ne. | 45 | n. | 12 | 7 | 14 | 10 | 5.4 | 0.0 | 0.0 |
| *Missouri Valley.* | | | | | | | **61.0** | **— 1.0** | | | | | | | | | | | **73** | **4.63** | **+ 0.4** | | | | | | | | | | **6.3** | | |
| Columbia, Mo. | 781 | 11 | 84 | 29.16 | 29.99 | + .05 | 63.0 | — 1.5 | 86 | 22 | 72 | 37 | 14 | 54 | 30 | ..... | ..... | ..... | 4.48 | — 0.4 | 17 | 5,683 | e. | 37 | nw. | 12 | 7 | 8 | 16 | 6.3 | 0.0 | 0.0 |
| Kansas City | 963 | 161 | 181 | 28.95 | 29.98 | + .06 | 63.3 | — 1.2 | 88 | 31 | 71 | 43 | 13 | 56 | 27 | 56 | 52 | 70 | 3.06 | — 2.0 | 11 | 8,832 | e. | 46 | nw. | 1 | 6 | 14 | 11 | 6.0 | 0.0 | 0.0 |
| St. Joseph | 967 | 11 | 49 | 29.95 | 29.98 | ..... | 63.0 | ..... | 86 | 22 | 72 | 44 | 1 | 54 | 30 | 56 | 51 | 69 | 1.61 | ..... | 12 | 6,195 | e. | 35 | nw. | 22 | 6 | 13 | 12 | 6.3 | 0.0 | 0.0 |
| Springfield, Mo. | 1,324 | 98 | 104 | 28.58 | 29.97 | + .04 | 65.0 | + 0.4 | 83 | 22 | 73 | 40 | 14 | 57 | 27 | 59 | 56 | 78 | 6.53 | + 1.0 | 19 | 7,209 | se. | 42 | nw. | 3 | 10 | 13 | 8 | 5.2 | 0.0 | 0.0 |
| Iola | 984 | 11 | 50 | 28.91 | 29.94 | + .02 | 66.2 | + 1.7 | 89 | 26 | 76 | 44 | 14 | 56 | 34 | ..... | ..... | ..... | 4.71 | — 0.3 | 16 | 5,152 | e. | 20 | n. | 26 | 2 | 19 | 10 | 6.7 | 0.0 | 0.0 |
| Topeka | 987 | 92 | 107 | ..... | ..... | ..... | 63.1 | — 1.9 | 89 | 31 | 72 | 42 | 14 | 54 | 32 | ..... | ..... | ..... | 2.23 | — 2.6 | 12 | 7,402 | se. | 34 | n. | 26 | 5 | 15 | 11 | 6.2 | 0.0 | 0.0 |
| Drexel | 1,299 | 10 | 53 | 28.60 | 30.00 | ..... | 59.3 | ..... | 83 | 22 | 68 | 37 | 14 | 50 | 31 | 54 | 51 | 77 | 3.13 | ..... | 11 | 8,101 | se. | 44 | e. | 11 | 7 | 12 | 12 | 6.2 | 0.0 | 0.0 |
| Lincoln | 1,189 | 11 | 84 | 28.72 | 29.97 | + .06 | 61.0 | — 1.9 | 85 | 22 | 70 | 43 | 1 | 52 | 34 | 53 | 50 | 72 | 3.77 | — 0.5 | 14 | 6,518 | e. | 35 | nw. | 22 | 2 | 12 | 17 | 7.1 | 0.0 | 0.0 |
| Omaha | 1,105 | 115 | 122 | 28.83 | 30.00 | + .08 | 61.7 | — 0.8 | 85 | 22 | 70 | 41 | 14 | 53 | 29 | 56 | 53 | 76 | 2.55 | — 2.0 | 10 | 5,608 | e. | 34 | nw. | 22 | 6 | 13 | 12 | 6.3 | 0.0 | 0.0 |
| Valentine | 2,598 | 47 | 54 | 27.27 | 29.98 | + .08 | 55.0 | — 2.9 | 83 | 24 | 65 | 37 | 23 | 45 | 37 | 49 | 44 | 72 | 8.18 | + 4.8 | 17 | 8,545 | s. | 43 | sw. | 9 | 7 | 13 | 11 | 6.2 | 0.0 | 0.0 |
| Sioux City | 1,135 | 94 | 164 | 28.81 | 30.02 | + .10 | 60.2 | — 0.4 | 84 | 22 | 70 | 39 | 14 | 51 | 29 | 54 | 48 | 68 | 3.82 | — 0.6 | 10 | 9,348 | e. | 45 | e. | 11 | 9 | 8 | 14 | 6.3 | 0.0 | 0.0 |
| Huron | 1,306 | 59 | 74 | 28.63 | 30.04 | + .12 | 57.1 | — 0.2 | 83 | 25 | 67 | 38 | 14 | 47 | 28 | 51 | 45 | 68 | 4.73 | + 1.8 | 14 | 8,606 | se. | 43 | ne. | 11 | 10 | 10 | 11 | 5.6 | 0.0 | 0.0 |
| Pierre | 1,572 | 70 | 75 | 28.32 | 29.98 | + .07 | 56.9 | — 2.4 | 85 | 21 | 66 | 40 | 12 | 48 | 32 | 53 | 49 | 78 | 5.11 | + 3.0 | 15 | 7,330 | se. | 47 | ne. | 11 | 10 | 5 | 16 | 6.1 | 0.0 | 0.0 |
| Yankton | 1,233 | 49 | 57 | 28.68 | 30.00 | + .08 | 59.7 | — 0.3 | 83 | 25 | 69 | 38 | 14 | 50 | 32 | ..... | ..... | ..... | 6.34 | + 2.4 | 10 | 6,216 | e. | 33 | s. | 22 | 3 | 12 | 16 | 7.1 | 0.0 | 0.0 |

TABLE I.—*Climatological data for Weather Bureau Stations, May, 1920*—Continued.

| Districts and stations. | Elevation of instruments. | | | Pressure. | | | Temperature of the air. | | | | | | | | | | Mean wet thermometer. | Mean temperature of the dew-point. | Mean relative humidity. | Precipitation. | | | Wind. | | | | | | Clear days | Partly cloudy days. | Cloudy days. | Average cloudiness, tenths. | Total snowfall. | Snow on ground at end of month. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Barometer above sea level. | Thermometer above ground. | Anemometer above ground. | Station, reduced to mean of 24 hours. | Sea level, reduced to mean of 24 hours. | Departure from normal. | Mean max. + mean min. ÷ 2. | Departure from normal. | Maximum. | Date. | Mean maximum. | Minimum. | Date. | Mean minimum. | Greatest daily range. | | | | | Total. | Departure from normal. | Days with 0.01 inch or more. | Total movement. | Prevailing direction. | Maximum velocity: Miles per hour. | Maximum velocity: Direction. | Maximum velocity: Date. | | | | | | |
| | *Ft.* | *Ft.* | *Ft.* | *In.* | *In.* | *In.* | ° *F.* | ° *F.* | °*F.* | | °*F.* | °*F.* | | °*F.* | °*F.* | | °*F.* | °*F.* | *U.* | *In.* | *In.* | | *Miles.* | | | | | | | | *0–10* | *In.* | *In.* |
| *Northern Slope.* | | | | | | | **50.7** | **− 1.8** | | | | | | | | | | | **64** | **2.90** | **+ 0.5** | | | | | | | | | | **5.8** | | |
| Billings | 3,140 | 5 | | 27.31 | 29.94 | + .04 | 53.7 | − 0.4 | 84 | 27 | 66 | 30 | 3 | 41 | 38 | | 44 | 35 | 59 | 1.39 | − 0.7 | 12 | 5,990 | sw. | 48 | sw. | 17 | 12 | 16 | 3 | 4.2 | T. | 0.0 |
| Havre | 2,505 | 11 | 44 | ..... | 29.95 | + .02 | 49.4 | − 2.2 | 78 | 27 | 60 | 26 | 2 | 39 | 36 | | ... | ... | ... | 2.54 | + 0.6 | 9 | 6,047 | sw. | 38 | sw. | 23 | 6 | 12 | 13 | .... | 2.0 | 0.0 |
| Helena | 4,110 | 87 | 112 | ..... | 29.95 | + .02 | 49.4 | − 2.2 | 78 | 27 | 60 | 26 | 2 | 39 | 36 | | ... | ... | ... | 2.54 | + 0.6 | 9 | 6,047 | sw. | 38 | sw. | 23 | 6 | 12 | 13 | .... | 2.0 | 0.0 |
| Kalispell | 2,973 | 48 | 56 | 26.89 | 29.95 | + .07 | 48.0 | − 3.0 | 73 | 8 | 58 | 31 | 26 | 38 | 35 | | 40 | 30 | 57 | 1.15 | − 0.9 | 9 | 4,902 | nw. | 38 | nw. | 17 | 7 | 13 | 11 | 5.6 | T. | 0.0 |
| Miles City | 2,371 | 26 | 48 | ..... | ..... | ..... | ..... | ..... | ... | ... | ... | ... | ... | ... | ... | | ... | ... | ... | ..... | ..... | ... | ..... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Rapid City | 3,259 | 50 | 58 | 26.59 | 30.00 | + .10 | 52.2 | − 2.0 | 85 | 21 | 61 | 32 | 12 | 43 | 40 | | 45 | 39 | 64 | 8.15 | + 5.2 | 14 | 7,391 | n. | 38 | nw. | 25 | 2 | 13 | 16 | 6.8 | T. | 0.0 |
| Cheyenne | 6,088 | 84 | 101 | 23.97 | 29.89 | + .04 | 49.4 | − 1.6 | 79 | 29 | 60 | 28 | 15 | 39 | 35 | | 42 | 37 | 68 | 2.15 | − 0.3 | 13 | 9,611 | s. | 44 | w. | 10 | 7 | 10 | 14 | 6.3 | T. | 0.0 |
| Lander | 5,372 | 60 | 68 | 24.60 | 29.92 | + .04 | 51.6 | − 0.4 | 82 | 28 | 63 | 31 | 4 | 40 | 40 | | 42 | 33 | 58 | 1.70 | − 1.2 | 11 | 4,342 | w. | 28 | w. | 1 | 12 | 10 | 9 | 5.1 | 0.0 | 0.0 |
| Sheridan | 3,790 | 10 | 47 | 26.06 | 29.95 | ..... | 51.2 | ..... | 81 | 21 | 62 | 31 | 3 | 40 | 47 | | 44 | 38 | 67 | 3.12 | ..... | 10 | 5,772 | nw. | 36 | se. | 1 | 10 | 11 | 10 | 5.4 | T. | 0.0 |
| Yellowstone Park | 6,200 | 11 | 48 | 23.83 | 29.94 | + .03 | 43.4 | − 4.0 | 67 | 27 | 54 | 24 | 3 | 32 | 34 | | 35 | 28 | 60 | 2.84 | + 0.9 | 11 | 6,157 | s. | 36 | sw. | 25 | 6 | 13 | 12 | 6.1 | 3.2 | 1.0 |
| North Platte | 2,821 | 11 | 51 | 27.07 | 29.98 | + .10 | 57.8 | − 1.2 | 83 | 10 | 68 | 37 | 8 | 48 | 35 | | 51 | 46 | 72 | 3.31 | + 0.2 | 12 | 6,093 | se. | 38 | sw. | 10 | 7 | 8 | 16 | 6.6 | 0.0 | 0.0 |
| *Middle Slope.* | | | | | | | **62.2** | **− 0.7** | | | | | | | | | | | **72** | **3.59** | **− 0.2** | | | | | | | | | | **6.3** | | |
| Denver | 5,292 | 106 | 113 | 24.68 | 29.88 | + .04 | 57.0 | + 0.3 | 88 | 25 | 68 | 35 | 13 | 46 | 37 | | 46 | 38 | 60 | 1.68 | − 0.9 | 9 | 5,888 | s. | 36 | s. | 21 | 5 | 14 | 12 | 6.4 | 0.0 | 0.0 |
| Pueblo | 4,685 | 80 | 86 | 25.22 | 29.87 | + .04 | 59.2 | − 0.3 | 90 | 31 | 73 | 33 | 14 | 46 | 41 | | 48 | 39 | 59 | 1.26 | − 0.4 | 10 | 5,319 | se. | 39 | e. | 5 | 9 | 9 | 13 | 6.1 | T. | 0.0 |
| Concordia | 1,392 | 50 | 58 | 28.50 | 29.96 | + .05 | 61.4 | − 2.3 | 87 | 31 | 71 | 40 | 1 | 52 | 9 | | 56 | 52 | 74 | 3.50 | − 1.2 | 11 | 6,272 | e. | 33 | nw. | 12 | 1 | 17 | 13 | 7.2 | 0.0 | 0.0 |
| Dodge City | 2,509 | 11 | 51 | 27.37 | 29.94 | + .07 | 61.6 | − 1.9 | 92 | 31 | 72 | 41 | 15 | 51 | 45 | | 55 | 51 | 74 | 3.47 | + 0.1 | 12 | 8,599 | ne. | 41 | sw. | 31 | 7 | 13 | 11 | 5.8 | 0.0 | 0.0 |
| Wichita | 1,358 | 139 | 158 | 28.51 | 29.93 | + .03 | 65.4 | − 0.5 | 90 | 26 | 74 | 45 | 15 | 56 | 37 | | 59 | 56 | 76 | 2.97 | − 2.0 | 11 | 9,410 | s. | 44 | sw. | 22 | 6 | 13 | 12 | 6.1 | 0.0 | 0.0 |
| Altus | 1,410 | 5 | ... | ..... | ..... | ..... | 68.8 | ..... | 98 | 3 | 80 | 45 | 17 | 58 | 45 | | ... | ... | ... | 5.00 | ..... | 9 | ..... | ne. | ... | ... | ... | ... | ... | ... | ..... | 0.0 | 0.0 |
| Broken Arrow | 765 | 11 | 52 | 29.11 | 29.92 | ..... | 68.8 | ..... | 90 | 3 | 78 | 46 | 15 | 60 | 32 | | 64 | 62 | 84 | 6.76 | ..... | 12 | 8,907 | s. | 40 | s. | 11 | 7 | 10 | 14 | 6.4 | 0.0 | 0.0 |
| Muskogee | 652 | 4 | ... | ..... | ..... | ..... | 71.3 | ..... | 93 | 26 | 82 | 45 | 13 | 61 | 29 | | ... | ... | ... | 4.20 | ..... | 7 | ..... | e. | ... | ... | ... | 14 | 5 | 12 | ..... | 0.0 | 0.0 |
| Oklahoma | 1,214 | 10 | 47 | 28.65 | 29.91 | + .02 | 68.6 | + 0.5 | 95 | 3 | 78 | 46 | 17 | 60 | 34 | | 62 | 59 | 78 | 8.66 | + 2.9 | 11 | 8,820 | s. | 36 | s. | 11 | 9 | 10 | 12 | 5.9 | 0.0 | 0.0 |
| *Southern Slope.* | | | | | | | **69.9** | **− 0.7** | | | | | | | | | | | **64** | **3.71** | **+ 1.0** | | | | | | | | | | **5.0** | | |
| Abilene | 1,738 | 10 | 52 | 28.10 | 29.87 | .00 | 72.0 | + 0.1 | 99 | 3 | 83 | 47 | 17 | 61 | 35 | | 60 | 58 | 70 | 8.26 | + 4.5 | 11 | 7,571 | s. | 42 | n. | 7 | 10 | 10 | 11 | 5.5 | 0.0 | 0.0 |
| Amarillo | 3,676 | 10 | 49 | 26.22 | 29.89 | + .05 | 64.1 | − 0.2 | 92 | 19 | 76 | 40 | 15 | 52 | 39 | | 55 | 50 | 68 | 2.57 | − 1.1 | 8 | 8,668 | s. | 31 | s. | 31 | 13 | 13 | 5 | 4.7 | 0.0 | 0.0 |
| Del Rio | 944 | 64 | 71 | 28.88 | 29.84 | − .01 | 76.3 | − 0.6 | 100 | 12 | 85 | 62 | 16 | 68 | 27 | | ... | ... | ... | 2.26 | − 0.1 | 6 | 7,450 | se. | 38 | e. | 13 | 9 | 9 | 13 | 5.9 | 0.0 | 0.0 |
| Roswell | 3,566 | 75 | 85 | 26.28 | 29.82 | .00 | 67.2 | − 2.2 | 95 | 19 | 82 | 46 | 15 | 53 | 43 | | 54 | 43 | 54 | 1.74 | + 0.6 | 6 | 5,936 | s. | 40 | nw. | 26 | 12 | 16 | 3 | 4.1 | 0.0 | 0.0 |
| *Southern Plateau.* | | | | | | | **69.6** | **+ 0.6** | | | | | | | | | | | **35** | **0.57** | **+ 0.3** | | | | | | | | | | **2.3** | | |
| El Paso | 3,762 | 110 | 133 | 26.08 | 29.75 | − .03 | 73.1 | + 1.0 | 95 | 20 | 87 | 52 | 16 | 59 | 37 | | 53 | 32 | 31 | 0.03 | − 0.3 | 1 | 8,567 | w. | 45 | w. | 10 | 23 | 6 | 2 | 2.6 | 0.0 | 0.0 |
| Santa Fe | 7,013 | 57 | 66 | 23.20 | 29.77 | − .04 | 56.2 | − 0.5 | 80 | 20 | 68 | 32 | 15 | 45 | 32 | | 43 | 30 | 45 | 2.28 | + 1.2 | 5 | 6,805 | sw. | 37 | s. | 13 | 17 | 5 | 9 | 4.7 | T. | 0.0 |
| Flagstaff | 6,908 | 8 | 57 | ..... | ..... | ..... | ..... | ..... | ... | ... | ... | ... | ... | ... | ... | | ... | ... | ... | ..... | ..... | ... | ..... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Phoenix | 1,108 | 76 | 81 | 28.62 | 29.75 | − .03 | 75.9 | + 1.1 | 105 | 19 | 92 | 50 | 6 | 59 | 44 | | 55 | 37 | 31 | 0.42 | + 0.4 | 1 | 4,046 | e. | 35 | w. | 21 | 26 | 5 | 0 | 1.1 | 0.0 | 0.0 |
| Yuma | 141 | 9 | 54 | 29.61 | 29.75 | − .04 | 77.6 | + 0.8 | 107 | 19 | 94 | 50 | 3 | 61 | 41 | | 59 | 44 | 40 | 0.00 | 0.0 | 0 | 3,905 | w. | 21 | s. | 20 | 30 | 1 | 0 | 0.4 | 0.0 | 0.0 |
| Independence | 3,957 | 9 | 41 | 25.86 | 29.83 | − .01 | 65.1 | + 0.6 | 94 | 19 | 80 | 39 | 1 | 50 | 36 | | 47 | 28 | 29 | 0.11 | 0.0 | 2 | 5,236 | nw. | 30 | se. | 8 | 21 | 9 | 1 | 2.8 | 0.0 | 0.0 |
| *Middle Plateau.* | | | | | | | **57.0** | **+ 0.5** | | | | | | | | | | | **43** | **0.79** | **− 0.4** | | | | | | | | | | **4.0** | | |
| Reno | 4,532 | 74 | 81 | 25.40 | 29.87 | − .04 | 56.0 | + 2.4 | 85 | 20 | 71 | 31 | 2 | 41 | 47 | | 43 | 32 | 48 | T. | − 0.8 | 0 | 5,408 | w. | 33 | w. | 23 | 20 | 7 | 4 | 3.1 | 0.0 | 0.0 |
| Tonopah | 6,090 | 12 | 20 | 23.98 | 29.80 | ..... | 57.0 | ..... | 84 | 20 | 70 | 31 | 2 | 44 | 34 | | 42 | 26 | 36 | 0.31 | − 1.1 | 2 | 7,197 | w. | 29 | nw. | 23 | 8 | 22 | 1 | 4.2 | 0.0 | 0.0 |
| Winnemucca | 4,344 | 18 | 56 | 25.55 | 29.91 | .00 | 54.2 | − 0.2 | 84 | 20 | 71 | 28 | 24 | 37 | 46 | | 40 | 26 | 42 | 0.15 | − 0.9 | 3 | 4,822 | ne. | 38 | sw. | 8 | 17 | 6 | 8 | 4.1 | 0.0 | 0.0 |
| Modena | 5,479 | 10 | 43 | 24.52 | 29.81 | − .01 | 54.4 | − 0.1 | 85 | 20 | 70 | 27 | 4 | 39 | 45 | | 40 | 26 | 42 | 1.67 | + 0.8 | 7 | 7,471 | sw. | 43 | sw. | 23 | 19 | 7 | 5 | 3.5 | 0.0 | 0.0 |
| Salt Lake City | 4,360 | 163 | 203 | 25.54 | 29.86 | .00 | 57.8 | − 0.5 | 82 | 28 | 67 | 40 | 2 | 48 | 31 | | 46 | 36 | 49 | 1.83 | − 0.1 | 9 | 6,238 | nw. | 44 | se. | 22 | 12 | 10 | 9 | 4.8 | 0.0 | 0.0 |
| Grand Junction | 4,602 | 60 | 68 | 25.27 | 29.80 | − .03 | 62.4 | + 0.8 | 88 | 29 | 76 | 40 | 6 | 49 | 38 | | 47 | 32 | 40 | 0.80 | − 0.1 | 5 | 5,358 | se. | 34 | sw. | 13 | 16 | 7 | 8 | 4.4 | 0.0 | 0.0 |
| *Northern Plateau.* | | | | | | | **54.0** | **− 2.9** | | | | | | | | | | | **52** | **1.05** | **− 0.7** | | | | | | | | | | **4.7** | | |
| Baker | 3,471 | 48 | 53 | 26.43 | 30.02 | + .06 | 48.0 | − 2.7 | 77 | 20 | 61 | 25 | 1 | 35 | 44 | | 39 | 31 | 58 | 1.27 | − 0.5 | 5 | 4,688 | se. | 20 | n. | 10 | 14 | 13 | 4 | 3.7 | T. | 0.0 |
| Boise | 2,739 | 78 | 86 | 27.11 | 29.96 | + .02 | 55.0 | − 2.6 | 81 | 20 | 68 | 32 | 2 | 42 | 40 | | 46 | 38 | 58 | 0.56 | − 0.7 | 3 | 4,462 | nw. | 27 | nw. | 23 | 19 | 10 | 2 | 2.9 | 0.0 | 0.0 |
| Lewiston | 757 | 40 | 42 | 29.20 | 30.01 | + .05 | 56.5 | − 4.3 | 82 | 8 | 68 | 38 | 24 | 45 | 36 | | ... | ... | ... | 1.54 | − 0.1 | 7 | 2,650 | e. | 27 | w. | 21 | 10 | 7 | 14 | 5.7 | 0.0 | 0.0 |
| Pocatello | 4,477 | 60 | 68 | 25.41 | 29.90 | + .01 | 53.6 | − 1.9 | 78 | 17 | 65 | 30 | 3 | 42 | 36 | | 42 | 31 | 50 | 1.36 | − 0.8 | 9 | 5,979 | sw. | 40 | s. | 23 | 6 | 17 | 8 | 5.8 | 0.0 | 0.0 |
| Spokane | 1,299 | 101 | 110 | 27.95 | 30.01 | + .05 | 53.0 | − 3.1 | 80 | 7 | 64 | 36 | 24 | 42 | 33 | | 43 | 32 | 53 | 1.02 | − 0.6 | 12 | 5,336 | sw. | 39 | sw. | 17 | 7 | 19 | 5 | 5.5 | 0.0 | 0.0 |
| Walla Walla | 991 | 57 | 65 | 28.94 | 30.01 | + .05 | 57.9 | − 2.8 | 84 | 7 | 69 | 41 | 24 | 47 | 33 | | 46 | 33 | 43 | 0.57 | − 1.3 | 7 | 4,018 | s. | 28 | nw. | 29 | 12 | 14 | 5 | 4.6 | 0.0 | 0.0 |
| *North Pacific Coast Region.* | | | | | | | **51.6** | **− 2.3** | | | | | | | | | | | **72** | **1.48** | **− 1.0** | | | | | | | | | | **5.0** | | |
| North Head | 211 | 11 | 56 | 29.90 | 30.14 | + .11 | 48.1 | − 3.1 | 63 | 6 | 51 | 42 | 12 | 45 | 18 | | 45 | 42 | 81 | 1.61 | − 0.8 | 12 | 11,785 | nw. | 50 | sw. | 16 | 6 | 20 | 5 | 5.0 | 0.0 | 0.0 |
| Port Angeles | 29 | 8 | 53 | 30.09 | 30.12 | ..... | 47.0 | ..... | 66 | 7 | 56 | 32 | 12 | 38 | 27 | | ... | ... | ... | 0.80 | − 0.5 | 8 | 6,068 | nw. | 34 | w. | 17 | 8 | 15 | 8 | 5.5 | 0.0 | 0.0 |
| Seattle | 125 | 215 | 250 | 29.98 | 30.11 | + .10 | 51.6 | − 3.4 | 79 | 7 | 60 | 40 | 10 | 44 | 30 | | 45 | 39 | 67 | 0.96 | − 1.4 | 13 | 6,648 | s. | 41 | sw. | 17 | 6 | 14 | 11 | 5.9 | 0.0 | 0.0 |
| Tacoma | 213 | 113 | 120 | 29.88 | 30.10 | + .08 | 51.8 | − 2.7 | 82 | 7 | 61 | 38 | 3 | 42 | 36 | | 47 | 43 | 74 | 1.81 | − 0.7 | 12 | 4,757 | n. | 27 | sw. | 23 | 7 | 17 | 7 | 5.8 | 0.0 | 0.0 |
| Tatoosh Island | 86 | 7 | 57 | 30.00 | 30.10 | + .09 | 47.8 | − 1.8 | 56 | 7 | 51 | 41 | 12 | 44 | 12 | | 45 | 43 | 85 | 4.00 | − 0.1 | 15 | 8,559 | w. | 72 | s. | 20 | 11 | 8 | 12 | 5.6 | 0.0 | 0.0 |
| Yakima | 1,071 | 4 | ... | ..... | ..... | ..... | ..... | ..... | ... | ... | ... | ... | ... | ... | ... | | ... | ... | ... | ..... | ..... | ... | ..... | ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| Medford | 1,425 | 4 | ... | ..... | ..... | ..... | 56.2 | ..... | 85 | 16 | 74 | 30 | 25 | 39 | 49 | | ... | ... | ... | 0.96 | ..... | 3 | ..... | nw. | ... | ... | ... | 15 | 7 | 9 | .... | 0.0 | 0.0 |
| Portland, Oreg | 153 | 68 | 106 | 29.94 | 30.10 | + .07 | 55.1 | − 1.7 | 87 | 7 | 66 | 38 | 3 | 44 | 35 | | 48 | 42 | 68 | 0.91 | − 1.4 | 9 | 4,279 | nw. | 28 | w. | 24 | 12 | 15 | 4 | 4.2 | 0.0 | 0.0 |
| Roseburg | 510 | 9 | 57 | 29.54 | 30.19 | + .07 | 55.0 | − 1.0 | 86 | 6 | 71 | 33 | 25 | 39 | 45 | | 46 | 37 | 60 | 0.24 | − 1.8 | 3 | 2,606 | n. | 15 | n. | 30 | 17 | 13 | 1 | 2.8 | 0.0 | 0.0 |
| *Middle Pacific Coast Region.* | | | | | | | **57.5** | **0.0** | | | | | | | | | | | **59** | **0.01** | **− 1.3** | | | | | | | | | | **2.8** | | |
| Eureka | 62 | 73 | 89 | 30.05 | 30.12 | + .07 | 49.3 | − 2.8 | 59 | 20 | 54 | 38 | 25 | 45 | 18 | | 46 | 44 | 82 | 0.04 | − 2.5 | 2 | 5,601 | n. | 36 | n. | 31 | 9 | 16 | 6 | 4.9 | 9.0 | 0.0 |
| Mount Tamalpais | 2,375 | 11 | 18 | 27.50 | 29.96 | − .04 | 56.7 | + 3.0 | 84 | 18 | 65 | 35 | 1 | 49 | 23 | | 46 | 36 | 50 | 0.00 | − 1.5 | 0 | 16,301 | nw. | 88 | nw. | 21 | 20 | 9 | 2 | 2.4 | 0.0 | 0.0 |
| Point Reyes Light | 490 | 7 | 18 | 29.41 | 29.93 | ..... | 49.0 | − 2.6 | 57 | 20 | 52 | 43 | 17 | 45 | 13 | | ... | ... | ... | T. | ..... | ... | 24,838 | nw. | 72 | nw. | 21 | 16 | 11 | 4 | 3.6 | 0.0 | 0.0 |
| Red Bluff | 332 | 50 | 56 | 29.55 | 29.90 | − .05 | 68.6 | + 2.1 | 97 | 18 | 83 | 44 | 2 | 55 | 38 | | 52 | 35 | 37 | T. | − 1.3 | 0 | 5,166 | nw. | 27 | nw. | 31 | 25 | 6 | 0 | 2.0 | 0.0 | 0.0 |
| Sacramento | 69 | 106 | 117 | 29.83 | 29.90 | − .04 | 65.0 | + 2.1 | 98 | 18 | 81 | 39 | 1 | 49 | 45 | | 52 | 41 | 53 | 0.00 | − 1.0 | 0 | 6,522 | s. | 28 | nw. | 31 | 24 | 7 | 0 | 1.8 | 0.0 | 0.0 |
| San Francisco | 155 | 208 | 243 | 29.80 | 29.97 | − .02 | 55.8 | + 0.3 | 75 | 19 | 63 | 45 | 2 | 49 | 25 | | 49 | 44 | 72 | T. | − 0.8 | 0 | 9,515 | sw. | 35 | w. | 26 | 22 | 6 | 3 | 2.6 | 0.0 | 0.0 |
| San Jose | 141 | 12 | 110 | 29.84 | 29.99 | ..... | 58.4 | − 2.3 | 90 | 18 | 73 | 36 | 2 | 44 | 41 | | ... | ... | ... | T. | − 0.7 | 0 | 4,465 | nw. | 23 | nw. | 26 | 24 | 5 | 2 | 2.0 | 0.0 | 0.0 |
| *South Pacific Coast Region.* | | | | | | | **62.0** | **− 0.1** | | | | | | | | | | | **66** | **0.14** | **− 0.5** | | | | | | | | | | **3.5** | | |
| Fresno | 327 | 89 | 98 | 29.53 | 29.89 | − .03 | 68.2 | − 0.2 | 98 | 18 | 83 | 42 | 2 | 53 | 37 | | 52 | 35 | 38 | 0.00 | − 0.6 | 0 | 7,477 | nw. | 26 | nw. | 24 | 27 | 4 | 0 | 1.0 | 0.0 | 0.0 |
| Los Angeles | 338 | 159 | 191 | 29.56 | 29.93 | − .02 | 62.1 | − 0.4 | 89 | 28 | 70 | 46 | 5 | 54 | 30 | | 55 | 52 | 77 | 0.10 | − 0.4 | 1 | 3,995 | sw. | 17 | w. | 16 | 15 | 8 | 8 | 4.1 | 0.0 | 0.0 |
| San Diego | 87 | 62 | 70 | 29.83 | 29.92 | − .03 | 59.8 | − 1.6 | 77 | 28 | 65 | 50 | 4 | 55 | 18 | | 55 | 52 | 80 | 0.44 | 0.0 | 4 | 4,970 | w. | 21 | s. | 20 | 9 | 9 | 13 | 6.0 | 0.0 | 0.0 |
| San Luis Obispo | 201 | 32 | 40 | 29.75 | 29.97 | − .03 | 57.8 | + 1.1 | 90 | 27 | 70 | 41 | 3 | 46 | 46 | | 49 | 44 | 70 | T. | − 0.9 | 0 | 3,464 | nw. | 16 | w. | 19 | 22 | 5 | 4 | 2.8 | 0.0 | 0.0 |
| *West Indies.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| San Juan, P. R | 82 | 8 | 54 | 29.87 | 29.95 | ..... | 79.7 | ..... | 92 | 30 | 86 | 70 | 3 | 73 | 19 | | ... | ... | ... | 4.71 | 0.0 | 11 | 8,505 | se. | 38 | e. | 12 | 9 | 17 | 5 | 5.1 | 0.0 | 0.0 |
| *Panama Canal.* | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Balboa Heights | 118 | 7 | 97 | 29.72 | 29.84 | .00 | 81.2 | + 0.6 | 93 | 6 | 88 | 72 | 27 | 74 | 17 | | 75 | 73 | 79 | 3.31 | − 4.9 | 9 | 5,792 | nw. | 26 | n. | 1 | 3 | 19 | 9 | 6.4 | 0.0 | 0.0 |
| Colon | 36 | 7 | 97 | 29.81 | 29.84 | .00 | 82.6 | + 2.1 | 93 | 19 | 88 | 73 | 24 | 77 | 18 | | 76 | 74 | 79 | 5.48 | − 7.0 | 11 | 7,435 | n. | 27 | s. | 25 | 1 | 19 | 11 | 6.6 | 0.0 | 0.0 |

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1920, at all stations furnished with self-registering gages.*

| Stations. | Date. | Total duration. | | Total amount of precipitation. | Excessive rate. | | Amount before excessive rate began. | Depths of precipitation (in inches) during periods of time indicated. | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From— | To— | | Began— | Ended— | | 5 min. | 10 min. | 15 min. | 20 min. | 25 min. | 30 min. | 35 min. | 40 min. | 45 min. | 50 min. | 60 min. | 80 min. | 100 min. | 120 min. |
| Abilene, Tex. | 7 | 1:20 p. m. | 3:00 p. m. | 1.70 | 1:35 p. m. | 2:00 p. m. | 0.01 | 0.21 | 0.70 | 1.23 | 1.54 | 1.63 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 9–10 | 5:35 p. m. | D. N. a. m. | 2.58 | 5:50 p. m. | 6:06 p. m. | 0.01 | 0.17 | 0.38 | 0.52 | 0.54 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 11 | D. N. a. m. | D. N. a. m. | 1.47 | 3:25 a. m. | 4:16 a. m. | 0.06 | 0.27 | 0.40 | 0.45 | 0.52 | 0.62 | 0.72 | 0.90 | 1.04 | 1.28 | 1.36 | 1.41 | .... | .... | .... |
| Albany, N. Y. | 21 | | | 0.18 | | | | | | | | | | | | | | 0.10 | .... | .... | .... |
| Alpena, Mich. | 17 | | | 0.32 | | | | | | | | | | | | | | 0.06 | .... | .... | .... |
| Amarillo, Tex. | 14 | | | 1.49 | | | | | | | | | | | | | | 0.20 | .... | .... | .... |
| Anniston, Ala. | 2 | 6:42 p. m. | 9:00 p. m. | 1.26 | 6:48 p. m. | 7:52 p. m. | 0.02 | 0.11 | 0.25 | 0.47 | 0.51 | 0.51 | 0.51 | 0.51 | 0.61 | 0.66 | 0.70 | 0.77 | 0.96 | 1.06 | .... |
| | 2–3 | 11:00 p. m. | 2:00 a. m. | 0.95 | 11:18 p. m. | 11:58 p. m. | 0.05 | 0.16 | 0.29 | 0.34 | 0.37 | 0.39 | 0.43 | 0.55 | 0.67 | .... | .... | .... | .... | .... | .... |
| | 13 | 1:00 a. m. | 9:45 a. m. | 1.63 | 3:31 a. m. | 3:57 a. m. | 0.04 | 0.28 | 0.48 | 0.55 | 0.61 | 0.67 | 0.70 | .... | .... | .... | .... | .... | .... | .... | .... |
| Asheville, N. C. | 13 | | | 0.33 | | | | | | | | | | | | | | 0.21 | .... | .... | .... |
| Atlanta, Ga. | 2 | | | 1.35 | | | | | | | | | | | | | | 0.59 | .... | .... | .... |
| Atlantic City, N. J. | 13 | | | 0.48 | | | | | | | | | | | | | | 0.31 | .... | .... | .... |
| Augusta, Ga. | 2 | | | 0.51 | | | | | | | | | | | | | | 0.34 | .... | .... | .... |
| Baker, Oreg. | 9 | | | 0.62 | | | | | | | | | | | | | | (*) | .... | .... | .... |
| Baltimore, Md. | 12 | | | 0.78 | | | | | | | | | | | | | | 0.37 | .... | .... | .... |
| Bentonville, Ark. | 6 | 2:35 p. m. | 4:25 p. m. | 0.59 | 3:03 p. m. | 3:19 p. m. | 0.02 | 0.26 | 0.40 | 0.50 | 0.53 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 20 | 3:30 a. m. | 4:45 a. m. | 1.04 | 4:07 a. m. | 4:36 a. m. | 0.20 | 0.15 | 0.36 | 0.51 | 0.65 | 0.76 | 0.84 | .... | .... | .... | .... | .... | .... | .... | .... |
| | 29 | 11:40 a. m. | 1:10 p. m. | 1.19 | 12:17 p. m. | 12:53 p. m. | 0.02 | 0.11 | 0.43 | 0.54 | 0.60 | 0.67 | 0.80 | 1.12 | 1.17 | .... | .... | .... | .... | .... | .... |
| Binghamton, N. Y. | 11 | | | 0.84 | | | | | | | | | | | | | | 0.14 | .... | .... | .... |
| Birmingham, Ala. | 12 | 6:53 p. m. | 9:47 p. m. | 1.57 | 8:07 p. m. | 8:55 p. m. | 0.12 | 0.06 | 0.14 | 0.25 | 0.37 | 0.45 | 0.54 | 0.88 | 1.24 | 1.36 | 1.40 | .... | .... | .... | .... |
| | 13 | D. N. a. m. | 9:40 a. m. | 2.37 | 4:23 a. m. | 4:44 a. m. | 1.07 | 0.21 | 0.25 | 0.44 | 0.53 | 0.55 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 21 | 4:10 a. m. | 6:07 a. m. | 0.65 | 4:18 a. m. | 4:41 a. m. | 0.02 | 0.11 | 0.23 | 0.37 | 0.46 | 0.54 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Bismarck, N. Dak. | 25 | | | 0.52 | | | | | | | | | | | | | | 0.35 | .... | .... | .... |
| Block Island, R. I. | 21 | | | 0.46 | | | | | | | | | | | | | | 18 | .... | .... | .... |
| Boise, Idaho. | 9 | | | 0.47 | | | | | | | | | | | | | | 0.21 | .... | .... | .... |
| Boston, Mass. | 22 | | | 3.23 | | | | | | | | | | | | | | 0.32 | .... | .... | .... |
| Buffalo, N. Y. | 19 | | | 0.39 | | | | | | | | | | | | | | 0.16 | .... | .... | .... |
| Burlington, Vt. | 20 | | | 0.62 | | | | | | | | | | | | | | 0.38 | .... | .... | .... |
| Cairo, Ill. | 30–31 | 8:36 p. m. | D. N. a. m. | 0.94 | 9:20 p. m. | 9:43 p. m. | 0.02 | 0.19 | 0.37 | 0.44 | 0.53 | 0.64 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Canton, N. Y. | 3 | | | 0.29 | | | | | | | | | | | | | | 0.18 | .... | .... | .... |
| Charles City, Iowa. | 18 | 6:21 p. m. | 7:28 p. m. | 0.88 | 6:22 p. m. | 7:03 p. m. | 0.01 | 0.30 | 0.44 | 0.59 | 0.60 | 0.64 | 0.68 | 0.73 | 0.82 | .... | .... | .... | .... | .... | .... |
| | 22 | 4:28 p. m. | 9:12 p. m. | 1.64 | 4:51 p. m. | 5:08 p. m. | 0.03 | 0.14 | 0.34 | 0.59 | 0.63 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | | | | | 6:27 p. m. | 6:52 p. m. | 0.70 | 0.23 | 0.34 | 0.54 | 0.73 | 0.82 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Charleston, S. C. | 8 | | | 0.57 | | | | | | | | | | | | | | 0.29 | .... | .... | .... |
| Charlotte, N. C. | 18 | | | 0.54 | | | | | | | | | | | | | | 0.19 | .... | .... | .... |
| Chattanooga, Tenn. | 24 | | | 0.73 | | | | | | | | | | | | | | 0.54 | .... | .... | .... |
| Cheyenne, Wyo. | 5 | | | 0.20 | | | | | | | | | | | | | | 0.12 | .... | .... | .... |
| Chicago, Ill. | 17 | | | 0.76 | | | | | | | | | | | | | | 0.17 | .... | .... | .... |
| Cincinnati, Ohio. | 23 | 5:40 p. m. | 7:20 p. m. | 1.04 | 5:57 p. m. | 6:20 p. m. | 0.01 | 0.18 | 0.50 | 0.74 | 0.91 | 0.93 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Cleveland, Ohio. | 23 | | | 0.30 | | | | | | | | | | | | | | 0.26 | .... | .... | .... |
| Columbia, Mo. | 11 | 3:02 p. m. | 4:00 p. m. | 0.66 | 3:05 p. m. | 3:17 p. m. | 0.01 | 0.14 | 0.45 | 0.50 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Columbia, S. C. | 13 | | | 0.89 | | | | | | | | | | | | | | 0.78 | .... | .... | .... |
| Columbus, Ohio. | 12 | | | 1.28 | | | | | | | | | | | | | | 0.23 | .... | .... | .... |
| Concord, N. H. | 22 | | | 1.12 | | | | | | | | | | | | | | 0.16 | .... | .... | .... |
| Concordia, Kans. | 12 | 12:56 p. m. | 1:32 p. m. | 0.75 | 1:04 p. m. | 1:23 p. m. | 0.01 | 0.16 | 0.30 | 0.54 | 0.73 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | | 4:17 p. m. | 5:58 p. m. | 1.11 | 5:10 p. m. | 5:35 p. m. | 0.10 | 0.07 | 0.49 | 0.77 | 0.92 | 0.96 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Corpus Christi, Tex. | 14 | 8:57 a. m. | 2:32 p. m. | 1.37 | 9:18 a. m. | 9:53 a. m. | 0.02 | 0.11 | 0.40 | 0.67 | 0.75 | 0.85 | 0.93 | 1.04 | .... | .... | .... | .... | .... | .... | .... |
| | 16 | D. N. a. m. | D. N. a. m. | 2.14 | 2:07 a. m. | 3:05 a. m. | 0.01 | 0.13 | 0.24 | 0.39 | 0.50 | 0.54 | 0.60 | 0.78 | 1.11 | 1.38 | 1.55 | 1.67 | .... | .... | .... |
| Dallas, Tex. | 4–5 | 10:30 p. m. | 1:25 a. m. | 2.00 | 10:43 p. m. | 11:07 p. m. | 0.02 | 0.25 | 0.97 | 1.54 | 1.78 | 1.88 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 5 | 8:10 p. m. | 11:03 p. m. | 1.86 | 8:35 p. m. | 9:10 p. m. | 0.03 | 0.11 | 0.37 | 0.63 | 1.13 | 1.41 | 1.58 | 1.67 | .... | .... | .... | .... | .... | .... | .... |
| | 11 | 6:16 a. m. | 10:22 a. m. | 1.51 | 8:50 a. m. | 9:45 a. m. | 0.17 | 0.06 | 0.12 | 0.16 | 0.30 | 0.51 | 0.53 | 0.54 | 0.55 | 0.60 | 1.04 | 1.35 | .... | .... | .... |
| | 15 | 7:12 a. m. | 2:37 p. m. | 1.37 | 10:49 a. m. | 11:45 a. m. | 0.29 | 0.15 | 0.32 | 0.46 | 0.59 | 0.60 | 0.61 | 0.63 | 0.74 | 0.77 | 0.82 | 0.98 | .... | .... | .... |
| Davenport, Iowa. | 11 | | | 0.65 | | | | | | | | | | | | | | 0.28 | .... | .... | .... |
| Dayton, Ohio. | 23 | 5:10 p. m. | 5:45 p. m. | 0.65 | 5:12 p. m. | 5:32 p. m. | 0.01 | 0.25 | 0.46 | 0.50 | 0.59 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Del Rio, Tex. | 13–14 | 7:01 p. m. | D. N. a. m. | 1.53 | 7:09 p. m. | 7:35 p. m. | 0.03 | 0.09 | 0.26 | 0.46 | 0.70 | 0.82 | 0.86 | .... | .... | .... | .... | .... | .... | .... | .... |
| Denver, Colo. | 5–6 | | | 0.61 | | | | | | | | | | | | | | (*) | .... | .... | .... |
| Des Moines, Iowa. | 11–12 | 11:30 a. m. | 1:03 p. m. | 2.70 | 2:38 p. m. | 3:02 p. m. | 0.34 | 0.08 | 0.16 | 0.27 | 0.59 | 0.70 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Detroit, Mich. | 10 | | | 0.11 | | | | | | | | | | | | | | 0.06 | .... | .... | .... |
| Devils Lake, N. Dak. | 25 | | | 0.66 | | | | | | | | | | | | | | 0.26 | .... | .... | .... |
| Dodge City, Kans. | 10–11 | 11:05 p. m. | D. N. a. m. | 0.64 | 11:12 p. m. | 11:33 p. m. | 0.03 | 0.11 | 0.22 | 0.41 | 0.52 | 0.55 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Drexel, Nebr. | 22 | | | 0.58 | | | | | | | | | | | | | | 0.56 | .... | .... | .... |
| Dubuque, Iowa. | 22 | 6:20 a. m. | 10:05 a. m. | 1.27 | 7:41 a. m. | 8:21 a. m. | 0.06 | 0.07 | 0.21 | 0.28 | 0.36 | 0.40 | 0.50 | 0.56 | 0.63 | .... | .... | .... | .... | .... | .... |
| Duluth, Minn. | 22 | | | 1.77 | | | | | | | | | | | | | | 0.61 | .... | .... | .... |
| Eastport, Me. | 8–9 | | | 0.81 | | | | | | | | | | | | | | (*) | .... | .... | .... |
| Elkins, W. Va. | 12 | | | 1.17 | | | | | | | | | | | | | | 0.39 | .... | .... | .... |
| Ellendale, N. Dak. | 25 | | | 0.56 | | | | | | | | | | | | | | 0.35 | .... | .... | .... |
| El Paso, Tex. | 21 | | | 0.03 | | | | | | | | | | | | | | 0.02 | .... | .... | .... |
| Erie, Pa. | 23 | | | 0.15 | | | | | | | | | | | | | | 0.14 | .... | .... | .... |
| Escanaba, Mich. | 22 | | | 0.36 | | | | | | | | | | | | | | 0.30 | .... | .... | .... |
| Eureka, Cal. | 8 | | | 0.02 | | | | | | | | | | | | | | 0.02 | .... | .... | .... |
| Evansville, Ind. | 12 | | | 1.51 | | | | | | | | | | | | | | 0.61 | .... | .... | .... |
| Fort Smith, Ark. | 30 | | | 0.35 | | | | | | | | | | | | | | 0.35 | .... | .... | .... |
| Fort Wayne, Ind. | 11 | | | 0.68 | | | | | | | | | | | | | | 0.19 | .... | .... | .... |
| Fort Worth, Tex. | 4–5 | 9:24 p. m. | D. N. a. m. | 2.10 | 10:07 p. m. | 10:44 p. m. | 0.01 | 0.28 | 0.64 | 1.09 | 1.32 | 1.45 | 1.54 | 1.63 | 1.72 | .... | .... | .... | .... | .... | .... |
| | 9–10 | 6:26 p. m. | 9:30 a. m. | 2.18 | 8:06 p. m. | 8:26 p. m. | 0.01 | 0.06 | 0.22 | 0.45 | 0.55 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Fresno, Calif. | (‡) | | | (‡) | | | | | | | | | | | | | | (‡) | .... | .... | .... |
| Galveston, Tex. | 16 | D. N. a. m. | 7:53 a. m. | 2.35 | 2:37 a. m. | 3:15 a. m. | 0.02 | 0.19 | 0.49 | 0.71 | 0.87 | 1.17 | 1.33 | 1.46 | 1.52 | .... | .... | .... | .... | .... | .... |
| Grand Haven, Mich. | 23 | | | 0.19 | | | | | | | | | | | | | | 0.23 | .... | .... | .... |
| Grand Junction, Colo. | 11 | | | 0.33 | | | | | | | | | | | | | | 0.16 | .... | .... | .... |
| Grand Rapids, Mich. | 11 | | | 0.43 | | | | | | | | | | | | | | 0.18 | .... | .... | .... |
| Green Bay, Wis. | 22 | | | 0.41 | | | | | | | | | | | | | | 0.20 | .... | .... | .... |
| Greenville, S. C. | 13 | | | 0.53 | | | | | | | | | | | | | | 0.24 | .... | .... | .... |
| Hannibal, Mo. | 11 | | | 0.60 | | | | | | | | | | | | | | 0.56 | .... | .... | .... |
| Harrisburg, Pa. | 1 | | | 0.36 | | | | | | | | | | | | | | 0.34 | .... | .... | .... |
| Hartford, Conn. | 8 | | | 1.13 | | | | | | | | | | | | | | 0.29 | .... | .... | .... |
| Hatteras, N. C. | 8 | | | 0.34 | | | | | | | | | | | | | | 0.18 | .... | .... | .... |
| Havre, Mont. | 10 | | | 0.23 | | | | | | | | | | | | | | 0.13 | .... | .... | .... |
| Helena, Mont. | | | | | | | | | | | | | | | | | | | | | |
| Houghton, Mich. | 20 | | | 0.22 | | | | | | | | | | | | | | 0.20 | .... | .... | .... |
| Houston, Tex. | 15–16 | 10:00 p. m. | 6:20 a. m. | 2.35 | 12:13 a. m. | 12:57 a. m. | 0.05 | 0.15 | 0.41 | 0.71 | 0.90 | 0.99 | 1.12 | 1.25 | 1.37 | 1.43 | .... | .... | .... | .... | .... |
| | 26 | 8:15 p. m. | 9:06 p. m. | 0.60 | 8:26 p. m. | 8:43 p. m. | 0.02 | 0.12 | 0.30 | 0.52 | 0.56 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 28 | 3:14 p. m. | 7:52 p. m. | 1.36 | 4:06 p. m. | 5:10 p. m. | 0.15 | 0.06 | 0.14 | 0.20 | 0.24 | 0.32 | 0.40 | 0.49 | 0.57 | 0.61 | 0.69 | 0.94 | 1.02 | .... | .... |
| Huron, S. Dak. | 10 | | | 0.62 | | | | | | | | | | | | | | 0.55 | .... | .... | .... |
| Independence, Calif. | 13 | | | 0.07 | | | | | | | | | | | | | | 0.06 | .... | .... | .... |
| Indianapolis, Ind. | 12 | | | 2.15 | | | | | | | | | | | | | | 0.42 | .... | .... | .... |
| Iola, Kans. | 18 | 8:25 p. m. | 9:40 p. m. | 0.71 | 8:28 p. m. | 8:53 p. m. | 0.01 | 0.09 | 0.29 | 0.45 | 0.52 | 0.57 | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| | 29 | 5:55 p. m. | 6:20 p. m. | 0.59 | 5:57 p. m. | 6:12 p. m. | 0.01 | 0.09 | 0.42 | 0.54 | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... | .... |
| Jacksonville, Fla. | 18–19 | 12:23 p. m. | D. N. a. m. | 5.36 | 9:39 p. m. | 11:19 p. m. | 2.77 | 0.10 | 0.20 | 0.34 | 0.47 | 0.57 | 0.60 | 0.66 | 0.77 | 0.88 | 0.99 | 1.13 | 1.62 | 1.83 | .... |
| Kalispell, Mont. | 3 | | | 0.20 | | | | | | | | | | | | | | 0.20 | .... | .... | .... |

* Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1920, at all stations furnished with self-registering gages*—Continued.

| Stations. | Date. | Total duration. | | Total amount of precipitation. | Excessive rate. | | Amount before excessive rate began. | Depths of precipitation (in inches) during periods of time indicated. | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | From— | To— | | Began— | Ended— | | 5 min. | 10 min. | 15 min. | 20 min. | 25 min. | 30 min. | 35 min. | 40 min. | 45 min. | 50 min. | 60 min. | 80 min. | 100 min. | 120 min. |
| Kansas City, Mo. | 13 | D. N.a.m. | 6:45 a.m. | 1.05 | 3:18 a.m. | 3:44 a.m. | 0.20 | 0.09 | 0.18 | 0.28 | 0.43 | 0.52 | 0.57 | | | | | | | | |
| | 27 | 10:20 a.m. | 12:40 p.m. | 1.29 | 11:02 a.m. | 12:14 p.m. | 0.11 | 0.08 | 0.17 | 0.29 | 0.40 | 0.49 | 0.54 | 0.63 | 0.71 | 0.78 | 0.80 | 0.99 | 1.18 | | |
| Keokuk, Iowa | 11 | | | 0.66 | | | | | | | | | | | | | | 0.51 | | | |
| Key West, Fla. | 17–18 | D. N.p.m. | 8:05 a.m. | 1.72 | 3:43 a.m. | 4:12 a.m. | 0.60 | 0.12 | 0.26 | 0.43 | 0.64 | 0.82 | 1.00 | | | | | | | | |
| Knoxville, Tenn. | 2 | | | 0.79 | | | | | | | | | | | | | | 0.34 | | | |
| La Crosse, Wis. | 18 | | | 0.61 | | | | | | | | | | | | | | 0.46 | | | |
| Lander, Wyo. | 11 | | | 0.81 | | | | | | | | | | | | | | 0.20 | | | |
| Lansing, Mich. | 11 | | | 0.32 | | | | | | | | | | | | | | 0.12 | | | |
| Lewiston, Idaho | 30 | | | 0.14 | | | | | | | | | | | | | | 0.12 | | | |
| Lexington, Ky. | 18 | | | 1.11 | | | | | | | | | | | | | | 0.35 | | | |
| Lincoln, Nebr. | 11–12 | 8:50 p.m. | D. N.a.m. | 1.26 | 8:52 p.m. | 9:40 p.m. | 0.01 | 0.07 | 0.26 | 0.32 | 0.33 | 0.33 | 0.42 | 0.56 | 0.70 | 0.80 | 0.86 | | | | |
| | 22 | 5:43 p.m. | 7:20 p.m. | 0.78 | 5:43 p.m. | 6:10 p.m. | 0.00 | 0.07 | 0.35 | 0.51 | 0.55 | 0.63 | 0.68 | | | | | | | | |
| Little Rock, Ark. | 11–12 | 8:40 p.m. | D. N.a.m. | 2.01 | 11:12 p.m. | 11:45 p.m. | 0.11 | 0.20 | 0.31 | 0.34 | 0.41 | 0.56 | 0.62 | 0.66 | | | | | | | |
| | 15–16 | 4:30 p.m. | 11:40 a.m. | 2.99 | 12:22 a.m. | 1:07 a.m. | 0.81 | 0.10 | 0.22 | 0.35 | 0.50 | 0.68 | 0.81 | 0.92 | 1.07 | 1.16 | | | | | |
| Los Angeles, Calif. | 21 | | | 0.10 | | | | | | | | | | | | | | 0.05 | | | |
| Louisville, Ky. | 12 | | | 0.47 | | | | | | | | | | | | | | 0.31 | | | |
| Ludington, Mich. | 22–23 | | | 0.92 | | | | | | | | | | | | | | 0.30 | | | |
| Lynchburg, Va. | 12 | | | 0.21 | | | | | | | | | | | | | | 0.20 | | | |
| Macon, Ga. | 25 | 4:30 p.m. | 6:00 p.m. | 0.76 | 5:00 p.m. | 5:14 p.m. | 0.20 | 0.18 | 0.45 | 0.55 | | | | | | | | | | | |
| Madison, Wis. | 22 | | | 1.05 | | | | | | | | | | | | | | 0.45 | | | |
| Marquette, Mich. | 20 | | | 0.44 | | | | | | | | | | | | | | 0.22 | | | |
| Memphis, Tenn. | 5 | D. N.a.m. | 10:55 a.m. | 1.62 | 7:02 a.m. | 7:30 a.m. | 0.30 | 0.06 | 0.16 | 0.36 | 0.55 | 0.71 | 0.78 | | | | | | | | |
| Meridian, Miss. | 12 | 5:10 p.m. | 7:00 p.m. | 0.91 | 5:20 p.m. | 5:41 p.m. | 0.03 | 0.12 | 0.19 | 0.44 | 0.76 | 0.84 | | | | | | | | | |
| Miami, Fla. | 6 | 12:06 p.m. | 1:08 p.m. | 0.78 | 12:17 p.m. | 12:41 p.m. | 0.01 | 0.09 | 0.30 | 0.50 | 0.59 | 0.71 | | | | | | | | | |
| | 16 | D. N.a.m. | 10:35 a.m. | 1.62 | 6:05 a.m. | 6:50 a.m. | 0.04 | 0.35 | 0.62 | 0.80 | 0.89 | 0.95 | 1.10 | 1.25 | 1.37 | 1.47 | | | | | |
| | 17–18 | D. N.p.m. | 2:25 p.m. | 2.72 | 10:00 a.m. | 10:22 a.m. | 1.86 | 0.13 | 0.22 | 0.33 | 0.55 | 0.61 | | | | | | | | | |
| Milwaukee, Wis. | 22–23 | | | 0.86 | | | | | | | | | | | | | | 0.54 | | | |
| Minneapolis, Minn. | 18 | | | 0.67 | | | | | | | | | | | | | | 0.48 | | | |
| Mobile, Ala. | 5 | 5:17 p.m. | 6:15 p.m. | 0.51 | 5:23 p.m. | 5:32 p.m. | 0.01 | 0.31 | 0.50 | | | | | | | | | | | | |
| | 25 | 7:30 p.m. | 9:45 p.m. | 0.88 | 8:17 p.m. | 8:52 p.m. | 0.06 | 0.17 | 0.31 | 0.51 | 0.62 | 0.63 | 0.73 | 0.78 | | | | | | | |
| Modena, Utah | 13 | | | 0.95 | | | | | | | | | | | | | | 0.37 | | | |
| Montgomery, Ala. | 3 | 8:50 a.m. | 9:30 a.m. | 0.58 | 8:50 a.m. | 9:03 a.m. | 0.00 | 0.16 | 0.49 | 0.53 | | | | | | | | | | | |
| Moorhead, Minn. | 25 | | | 0.54 | | | | | | | | | | | | | | 0.53 | | | |
| Mount Tamalpais, Calif. | (‡) | | | (‡) | | | | | | | | | | | | | | (‡) | | | |
| Nantucket, Mass. | 9 | | | 0.71 | | | | | | | | | | | | | | 0.20 | | | |
| Nashville, Tenn. | 21 | 5:15 a.m. | 6:20 a.m. | 0.67 | 5:19 a.m. | 5:30 a.m. | 0.01 | 0.23 | 0.63 | 0.66 | | | | | | | | | | | |
| New Haven, Conn. | 21 | | | 0.82 | | | | | | | | | | | | | | 0.41 | | | |
| New Orleans, La. | 16–17 | 9:23 a.m. | D. N.a.m. | 2.32 | 10:32 a.m. | 11:10 a.m. | 1.11 | 0.11 | 0.21 | 0.35 | 0.42 | 0.53 | 0.60 | 0.71 | 0.77 | | | | | | |
| New York, N. Y. | 21 | | | 0.98 | | | | | | | | | | | | | | 0.47 | | | |
| Norfolk, Va. | 21 | | | 0.54 | | | | | | | | | | | | | | 0.53 | | | |
| Northfield, Vt. | 21 | | | 0.73 | | | | | | | | | | | | | | 0.22 | | | |
| North Head, Wash. | 17 | | | 0.26 | | | | | | | | | | | | | | 0.19 | | | |
| North Platte, Nebr. | 24 | 10:18 p.m. | 11:20 p.m. | 1.35 | 10:25 p.m. | 11:05 p.m. | 0.02 | 0.06 | 0.12 | 0.18 | 0.45 | 0.73 | 1.00 | | | | | | | | |
| Oklahoma, Okla. | 11 | D. N.a.m. | 7:20 a.m. | 2.84 | 3:40 a.m. | 4:00 a.m. | 0.01 | 0.13 | 0.51 | 0.75 | 0.81 | | | | | | | | | | |
| | | | | | 5:16 a.m. | 5:33 a.m. | 1.24 | 0.21 | 0.71 | 1.07 | 1.14 | | | | | | | | | | |
| Omaha, Nebr. | 22 | 6:00 p.m. | 7:45 p.m. | 0.58 | 6:14 p.m. | 6:36 p.m. | 0.01 | 0.14 | 0.29 | 0.42 | 0.48 | 0.54 | | | | | | | | | |
| Oswego, N. Y. | 14 | | | 0.10 | | | | | | | | | | | | | | 0.06 | | | |
| Palestine, Tex. | 15–16 | 7:30 p.m. | D. N.a.m. | 1.82 | 8:07 p.m. | 9:14 p.m. | 0.05 | 0.06 | 0.10 | 0.15 | 0.20 | 0.27 | 0.32 | 0.35 | 0.41 | 0.50 | 0.59 | 0.85 | 1.06 | | |
| Parkersburg, W. Va. | 12 | | | 1.07 | | | | | | | | | | | | | | 0.27 | | | |
| Pensacola, Fla. | 7 | 7:25 p.m. | 9:30 p.m. | 1.14 | 8:22 p.m. | 8:50 p.m. | 0.09 | 0.11 | 0.34 | 0.60 | 0.82 | 0.93 | 1.00 | | | | | | | | |
| | 25 | 3:50 p.m. | 5:00 p.m. | 1.08 | 4:33 p.m. | 4:55 p.m. | 0.08 | 0.11 | 0.33 | 0.71 | 0.94 | 0.99 | | | | | | | | | |
| Peoria, Ill. | 22 | | | 0.28 | | | | | | | | | | | | | | 0.27 | | | |
| Philadelphia, Pa. | 8 | | | 0.83 | | | | | | | | | | | | | | 0.22 | | | |
| Phoenix, Ariz. | 21 | | | 0.42 | | | | | | | | | | | | | | 0.27 | | | |
| Pierre, S. Dak. | 25 | | | 0.60 | | | | | | | | | | | | | | 0.49 | | | |
| Pittsburgh, Pa. | 21 | | | 0.20 | | | | | | | | | | | | | | 0.18 | | | |
| Pocatello, Idaho | 23 | | | 0.50 | | | | | | | | | | | | | | 0.22 | | | |
| Point Reyes Light, Calif. | 9 | | | T. | | | | | | | | | | | | | | T. | | | |
| Port Angeles, Wash. | 28 | | | 0.22 | | | | | | | | | | | | | | 0.10 | | | |
| Port Huron, Mich. | 19 | | | 0.19 | | | | | | | | | | | | | | 0.12 | | | |
| Portland, Me. | 22 | | | 1.79 | | | | | | | | | | | | | | 0.28 | | | |
| Portland, Oreg. | 17 | | | 0.50 | | | | | | | | | | | | | | 0.19 | | | |
| Providence, R. I. | 22 | | | 1.60 | | | | | | | | | | | | | | 0.39 | | | |
| Pueblo, Colo. | 30 | | | 0.12 | | | | | | | | | | | | | | 0.12 | | | |
| Raleigh, N. C. | 13 | | | 0.41 | | | | | | | | | | | | | | 0.39 | | | |
| Rapid City, S. Dak. | 11 | | | 2.92 | | | | | | | | | | | | | | 0.53 | | | |
| Reading, Pa. | 1 | | | 0.24 | | | | | | | | | | | | | | 0.20 | | | |
| Red Bluff, Calif. | 12 | | | T. | | | | | | | | | | | | | | T. | | | |
| Reno, Nev. | 4 | | | T. | | | | | | | | | | | | | | T. | | | |
| Richmond, Va. | 21 | 12:40 p.m. | D. N.p.m. | 1.76 | 4:19 p.m. | 4:33 p.m. | 0.33 | 0.15 | 0.38 | 0.51 | | | | | | | | | | | |
| | | | | | 9:55 p.m. | 10:14 p.m. | 1.02 | 0.26 | 0.54 | 0.67 | 0.72 | | | | | | | | | | |
| Rochester, N. Y. | 20 | | | 0.44 | | | | | | | | | | | | | | 0.40 | | | |
| Roseburg, Oreg. | 17 | | | 0.20 | | | | | | | | | | | | | | 0.15 | | | |
| Roswell, N. Mex. | 26 | 12:01 p.m. | 1:54 p.m. | 1.00 | 1:10 p.m. | 1:25 p.m. | 0.03 | 0.19 | 0.67 | 0.94 | | | | | | | | | | | |
| Sacramento, Calif. | ‡ | | | ‡ | | | | | | | | | | | | | | ‡ | | | |
| Saginaw, Mich. | 17 | | | 0.57 | | | | | | | | | | | | | | 0.10 | | | |
| St. Joseph, Mo. | 19 | | | 0.51 | | | | | | | | | | | | | | 0.49 | | | |
| St. Louis, Mo. | 2 | | | 1.52 | | | | | | | | | | | | | | 0.68 | | | |
| St. Paul, Minn. | 18 | | | 0.61 | | | | | | | | | | | | | | 0.52 | | | |
| Salt Lake City, Utah | 21 | | | 0.99 | | | | | | | | | | | | | | 0.29 | | | |
| San Antonio, Tex. | 13–14 | 9:43 p.m. | 1:48 a.m. | 1.82 | 9:51 p.m. | 11:08 p.m. | 0.08 | 0.08 | 0.16 | 0.24 | 0.25 | 0.27 | 0.33 | 0.40 | 0.47 | 0.50 | 0.57 | 0.77 | 1.36 | | |
| San Diego, Calif. | 21 | | | 0.24 | | | | | | | | | | | | | | 0.17 | | | |
| Sand Key, Fla. | 18 | 2:45 a.m. | D. N.a.m. | 0.70 | 2:58 a.m. | 3:24 a.m. | 0.02 | 0.14 | 0.32 | 0.49 | 0.59 | 0.64 | 0.67 | | | | | | | | |
| Sandusky, Ohio | 20 | | | 0.64 | | | | | | | | | | | | | | 0.55 | | | |
| Sandy Hook, N. J. | 21 | | | 0.46 | | | | | | | | | | | | | | 0.25 | | | |
| San Francisco, Calif. | 12 | | | T. | | | | | | | | | | | | | | T. | | | |
| San Jose, Calif. | 12 | | | T. | | | | | | | | | | | | | | T. | | | |
| San Luis Obispo, Calif. | 21 | | | T. | | | | | | | | | | | | | | T. | | | |
| Santa Fe, N. Mex. | 21 | 11:55 a.m. | 6:20 p.m. | 1.22 | 12:10 p.m. | 12:25 p.m. | T. | 0.15 | 0.36 | 0.55 | | | | | | | | | | | |
| Sault Ste. Marie, Mich. | 19 | | | 0.68 | | | | | | | | | | | | | | 0.30 | | | |
| Savannah, Ga. | 5 | | | 0.68 | | | | | | | | | | | | | | 0.52 | | | |
| Scranton, Pa. | 21 | 7:05 p.m. | 7:55 p.m. | 0.62 | 7:16 p.m. | 7:27 p.m. | 0.02 | 0.24 | 0.57 | 0.59 | | | | | | | | | | | |
| Seattle, Wash. | 17 | | | 0.24 | | | | | | | | | | | | | | 0.15 | | | |
| Sheridan, Wyo. | 11 | | | 1.11 | | | | | | | | | | | | | | 0.17 | | | |
| Shreveport, La. | 6 | D. N.a.m. | D. N.a.m. | 1.01 | 12:37 a.m. | 12:57 a.m. | 0.01 | 0.32 | 0.60 | 0.76 | 0.82 | | | | | | | | | | |
| | 7 | 12:35 a.m. | 7:20 a.m. | 1.32 | 12:37 a.m. | 1:02 a.m. | 0.01 | 0.14 | 0.35 | 0.49 | 0.77 | 0.94 | | | | | | | | | |
| Sioux City, Iowa | 11–12 | 11:10 p.m. | D. N.a.m. | 1.27 | 12:13 a.m. | 12:44 a.m. | 0.12 | 0.13 | 0.20 | 0.26 | 0.33 | 0.47 | 0.60 | 0.64 | | | | | | | |
| Spokane, Wash. | 2 | | | 0.38 | | | | | | | | | | | | | | (*) | | | |
| Springfield, Ill. | 11–12 | 8:07 p.m. | 11:36 a.m. | 3.91 | 9:42 p.m. | 10:00 p.m. | 0.17 | 0.19 | 0.32 | 0.56 | 0.63 | | | | | | | | | | |

¹ From defective automatic record. * Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE II.—*Accumulated amounts of precipitation for each 5 minutes, for the principal storms in which the rate of fall equaled or exceeded 0.25 inch in any 5 minutes, or 0.80 in 1 hour, during May, 1920, at all stations furnished with self-registering gages*—Continued.

| Stations. | Date. | Total duration. From— | Total duration. To— | Total amount of precipitation. | Excessive rate. Began— | Excessive rate. Ended— | Amount before excessive rate began. | Depths of precipitation (in inches) during periods of time indicated. 5 min. | 10 min. | 15 min. | 20 min. | 25 min. | 30 min. | 35 min. | 40 min. | 45 min. | 50 min. | 60 min. | 80 min. | 100 min. | 120 min. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Springfield, Mo. | 3 | 9;53 p. m. | 10:02 p. m. | 0.71 | 9:55 p. m. | 10:07 p. m. | 0.02 | 0.28 | 0.51 | 0.60 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 19–20 | 9:20 p. m. | D. N. a. m. | 1.77 | 10:21 p. m. | 10:42 p. m. | 0.06 | 0.12 | 0.36 | 0.58 | 0.66 | 0.70 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 27–28 | D. N. p. m. | D. N. a. m. | 0.73 | 11:45 p. m. | 12:05 a. m. | 0.05 | 0.11 | 0.31 | 0.40 | 0.59 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Syracuse, N. Y. | 21 | ..... | ..... | 0.08 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.05 | ..... | ..... | ..... |
| Tacoma, Wash. | 29 | ..... | ..... | 0.63 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.22 | ..... | ..... | ..... |
| Tampa, Fla. | 3 | ..... | ..... | 0.61 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.53 | ..... | ..... | ..... |
| Tatoosh Island, Wash. | 16 | ..... | ..... | 1.06 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.20 | ..... | ..... | ..... |
| Taylor, Tex. | 10 | 7:26 a. m. | 9:30 a. m. | 1.39 | 7:26 a. m. | 7:56 a. m. | T. | 0.19 | 0.43 | 0.56 | 0.71 | 0.84 | 0.89 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 13–14 | 8:25 p. m. | 7:50 a. m. | 1.42 | 11:37 p. m. | 11:57 p. m. | 0.09 | 0.07 | 0.28 | 0.53 | 0.60 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 15 | 6:10 p. m. | 8:45 p. m. | 1.85 | 6:28 p. m. | 7:33 p. m. | 0.04 | 0.06 | 0.09 | 0.15 | 0.25 | 0.33 | 0.46 | 0.51 | 0.64 | 0.86 | 1.10 | 1.64 | 1.77 | ..... | ..... |
| Terre Haute, Ind. | 11–12 | 10:50 p. m | 1:58 p. m. | 3.24 | 4:42 a. m. | 6:06 a. m. | 0.72 | 0.14 | 0.26 | 0.44 | 0.53 | 0.59 | 0.61 | 0.63 | 0.65 | 0.70 | 0.91 | 1.04 | 1.37 | 1.54 | ..... |
| Thomasville, Ga. | 25 | ..... | ..... | 0.63 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.46 | ..... | ..... | ..... |
| Toledo, Ohio | 19 | ..... | ..... | 0.38 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.31 | ..... | ..... | ..... |
| Tonopah, Nev. | 13 | ..... | ..... | 0.28 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.19 | ..... | ..... | ..... |
| Topeka, Kans. | 26 | ..... | ..... | 0.80 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.49 | ..... | ..... | ..... |
| Trenton, N. J. | 21 | ..... | ..... | 0.38 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.34 | ..... | ..... | ..... |
| Valentine, Nebr. | 25 | 11:58 a. m. | 1:40 p. m. | 1.02 | 12:46 p. m. | 1:12 p. m. | 0.20 | 0.08 | 0.19 | 0.32 | 0.59 | 0.80 | 0.82 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 25–26 | 7:45 p. m. | 1:40 a. m. | 3.16 | 8:32 p. m. | 9:39 p. m. | 0.15 | 0.21 | 0.43 | 0.63 | 0.64 | 0.78 | 1.00 | 1.14 | 1.27 | 1.40 | 1.52 | 1.80 | 1.97 | ..... | ..... |
| | | | | | 10:39 p. m. | 10:53 p. m. | 2.13 | 0.26 | 0.46 | 0.58 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Vicksburg, Miss. | 28 | 2:18 p. m. | 3:25 p. m. | 1.60 | 2:24 p. m. | 2:51 p. m. | 0.03 | 0.37 | 0.72 | 1.11 | 1.31 | 1.47 | 1.53 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Walla Walla, Wash. | 17 | ..... | ..... | 0.17 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.10 | ..... | ..... | ..... |
| Washington, D. C. | 12 | ..... | ..... | 0.70 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.42 | ..... | ..... | ..... |
| Wausau, Wis. | 22 | 7:15 p. m. | 11:48 p. m. | 0.77 | 7:19 p. m. | 7:34 p. m. | 0.02 | 0.31 | 0.45 | 0.52 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Wichita, Kans. | 19 | 4:40 a. m. | 5:15 a. m. | 1.26 | 4:46 a. m. | 5:03 a. m. | 0.04 | 0.21 | 0.56 | 1.12 | 1.21 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Williston, N. Dak. | 25 | ..... | ..... | 0.38 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.30 | ..... | ..... | ..... |
| Wilmington, N. C. | 13 | ..... | ..... | 0.25 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.24 | ..... | ..... | ..... |
| Winnemucca, Nev. | 10 | ..... | ..... | 0.07 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.02 | ..... | ..... | ..... |
| Wytheville, Va. | 12 | ..... | ..... | 0.26 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.23 | ..... | ..... | ..... |
| Yankton, S. Dak. | 11–12 | 12:55 p. m. | 4:45 a. m. | 2.54 | 8:12 p. m. | 8:42 p. m. | 0.63 | 0.14 | 0.19 | 0.25 | 0.35 | 0.46 | 0.52 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | 26 | 12:05 a. m. | 5:30 a. m. | 2.94 | 12:33 a. m. | 1:03 a. m. | 0.15 | 0.10 | 0.23 | 0.54 | 0.79 | 0.86 | 0.94 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| | | | | | 2:11 a. m. | 2:56 a. m. | 1.28 | 0.22 | 0.49 | 0.68 | 0.84 | 0.94 | 1.03 | 1.10 | 1.14 | 1.20 | ..... | ..... | ..... | ..... | ..... |
| Yellowstone Park, Wyo. | 23 | ..... | ..... | 0.69 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 0.25 | ..... | ..... | ..... |

*Self-register not in use. † Record partly estimated. ‡ No precipitation occurred during month.

TABLE III.—*Data furnished by the Canadian Meteorological Service, May, 1920.*

| Stations. | Altitude above mean sea level Jan. 1, 1919. | Pressure. Station reduced to mean of 24 hours. | Pressure. Sea level reduced to mean of 24 hours. | Pressure. Departure from normal. | Temperature of the air. Mean max. + mean min. ÷2 | Temperature of the air. Departure from normal. | Temperature of the air. Mean maximum. | Temperature of the air. Mean minimum. | Temperature of the air. Highest. | Temperature of the air. Lowest. | Precipitation. Total. | Precipitation. Departure from normal. | Precipitation. Total snowfall. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Feet.* | *Inches.* | *Inches.* | *Inches.* | °*F.* | °*F.* | °*F.* | °*F.* | °*F.* | °*F.* | *Inches.* | *Inches.* | *Inches.* |
| St. Johns, N. F. | 125 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Sydney, C. B. I. | 48 | 30.04 | 30.09 | +.12 | 45.8 | +0.6 | 57.1 | 34.5 | 76 | 26 | 2.38 | −1.39 | 0.0 |
| Halifax, N. S. | 88 | 29.96 | 30.07 | +.09 | 46.9 | −1.5 | 57.0 | 36.9 | 74 | 25 | 1.19 | −3.07 | 0.0 |
| Yarmouth, N. S. | 65 | 29.97 | 30.04 | +.06 | 47.1 | −0.5 | 54.9 | 39.4 | 72 | 29 | 2.35 | −1.45 | 0.0 |
| Charlottetown, P. E. I. | 38 | 30.00 | 30.04 | +.08 | 49.2 | +2.3 | 58.6 | 40.0 | 75 | 29 | 1.06 | −1.85 | T. |
| Chatham, N. B. | 28 | 30.02 | 30.05 | +.10 | 51.8 | +3.3 | 64.1 | 39.6 | 90 | 29 | 1.08 | −2.13 | 0.0 |
| Father Point, Que. | 20 | 29.99 | 30.01 | +.08 | 45.8 | +1.8 | 54.6 | 37.0 | 69 | 28 | 0.30 | −2.28 | 0.0 |
| Quebec, Que. | 296 | 29.71 | 30.03 | +.09 | 53.6 | +3.7 | 64.3 | 42.9 | 83 | 30 | 1.85 | −1.23 | 0.1 |
| Montreal, Que. | 187 | 29.82 | 30.02 | +.08 | 57.1 | +2.4 | 65.8 | 48.4 | 83 | 35 | 0.72 | −2.23 | 0.0 |
| Stonecliffe, Ont. | 489 | 29.43 | 30.04 | +.11 | 48.9 | −3.4 | 68.1 | 29.7 | 90 | 20 | 0.94 | −1.57 | 0.8 |
| Ottawa, Ont. | 236 | 29.78 | 30.04 | +.10 | 56.5 | +1.6 | 68.6 | 44.4 | 84 | 33 | 0.51 | −2.08 | T. |
| Kingston, Ont. | 285 | 29.74 | 30.05 | +.09 | 52.7 | −0.2 | 60.9 | 44.6 | 73 | 34 | 0.25 | −2.43 | 0.0 |
| Toronto, Ont. | 379 | 29.67 | 30.08 | +.10 | 54.4 | +1.2 | 65.2 | 43.7 | 83 | 31 | 0.39 | −2.65 | 0.0 |
| Cochrane, Ont. | 930 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| White River, Ont. | 1,244 | 28.73 | 30.05 | +.10 | 46.2 | +0.5 | 60.9 | 31.6 | 80 | 19 | 1.38 | −0.57 | 0.2 |
| Port Stanley, Ont. | 592 | 29.45 | 30.09 | +.12 | 51.0 | −2.1 | 61.0 | 41.0 | 74 | 26 | 1.00 | −2.18 | 0.0 |
| Southampton, Ont. | 656 | 29.37 | ..... | ..... | 48.1 | −2.6 | 57.4 | 38.8 | 76 | 27 | 0.43 | −2.01 | 0.0 |
| Parry Sound, Ont. | 688 | 29.40 | 30.10 | +.15 | 51.4 | +0.3 | 63.3 | 39.6 | 78 | 28 | 0.44 | −2.49 | 0.0 |
| Port Arthur, Ont. | 644 | 29.37 | 30.09 | +.13 | 47.8 | +1.9 | 58.2 | 37.4 | 71 | 27 | 1.36 | −0.79 | 0.0 |
| Winnipeg, Man. | 760 | 29.20 | 30.04 | +.08 | 54.3 | +2.7 | 67.9 | 40.8 | 82 | 23 | 1.51 | −0.77 | 0.0 |
| Minnedosa, Man. | 1,690 | 28.19 | 30.00 | +.04 | 52.2 | +3.8 | 66.2 | 38.3 | 80 | 26 | 1.68 | +0.23 | 0.0 |
| Le Pas, Man. | 860 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Qu'Appelle, Sask. | 2,115 | 27.70 | 29.94 | −0.6 | 51.7 | +1.9 | 65.0 | 38.5 | 77 | 28 | 1.67 | +0.02 | 0.0 |
| Medicine Hat, Alb. | 2,144 | 27.58 | 29.83 | −.00 | 54.9 | +0.8 | 67.5 | 42.4 | 82 | 31 | 1.28 | −0.03 | 0.0 |
| Moose Jaw, Sask. | 1,759 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Swift Current, Sask. | 2,392 | 27.31 | 29.92 | .00 | 53.3 | +2.6 | 66.9 | 39.8 | 80 | 29 | 2.13 | +0.37 | 1.7 |
| Calgary, Alb. | 3,428 | 26.38 | 29.94 | +.06 | 46.8 | −2.2 | 59.9 | 33.8 | 76 | 17 | 0.91 | −0.86 | 5.0 |
| Banff, Alb. | 4,521 | 25.35 | 29.94 | +.06 | 42.0 | −5.0 | 53.3 | 30.6 | 70 | 23 | 1.25 | −0.79 | 5.6 |
| Edmonton, Alb. | 2,150 | 27.62 | 29.89 | +.01 | 48.6 | −2.2 | 60.2 | 37.0 | 79 | 29 | 2.43 | +0.88 | 4.3 |
| Prince Albert, Sask. | 1,450 | 28.37 | 29.94 | −.01 | 51.7 | +4.1 | 65.2 | 38.2 | 84 | 21 | 1.50 | +0.24 | 0.0 |
| Battleford, Sask. | 1,592 | 28.16 | 29.89 | −.03 | 52.5 | +1.5 | 65.1 | 40.0 | 83 | 27 | 2.51 | +0.89 | 0.0 |
| Kamloops, B. C. | 1,262 | 28.72 | 30.00 | +.11 | 54.5 | −4.6 | 68.5 | 40.6 | 84 | 32 | 0.11 | −1.13 | 0.0 |
| Victoria, B. C. | 230 | 29.82 | 30.08 | +.08 | 49.8 | −2.7 | 57.1 | 42.9 | 67 | 40 | 1.37 | −0.11 | 0.0 |
| Barkerville, B. C. | 4,180 | 25.60 | 29.91 | +.07 | 38.2 | −7.3 | 48.5 | 28.0 | 58 | 19 | 2.70 | +0.18 | 13.4 |
| Triangle Island, B. C. | 680 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Prince Rupert, B. C. | 170 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Hamilton, Ber. | 151 | 29.85 | 30.01 | −.05 | 66.4 | −3.0 | 71.9 | 60.8 | 79 | 52 | 8.46 | +3.80 | 0.0 |

# SEISMOLOGICAL REPORTS.

W. J. HUMPHREYS, Professor in Charge.

[Weather Bureau, Washington, D. C., July 3, 1920.]

TABLE I.—*Noninstrumental earthquake reports, May, 1920.*

| Day. | Approximate time, Greenwich civil. | Station. | Approximate latitude. | Approximate longitude. | Intensity Rossi-Forel. | Number of shocks. | Duration. | Sounds. | Remarks. | Observer. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1920. | *H. m.* | CALIFORNIA. | ° ′ | ° ′ | | | *Sec.* | | | |
| May 7 | 1 59 | San Luis Obispo | 35 13 | 120 45 | 4 | 1 | 5 | None | Felt by many | J. E. Hissong. |
| 18 | 6 25 | El Centro | 32 50 | 115 35 | 5 | 2 | 2<br>10 | do | Alarmed many | J. M. Bartley. |
| | | Warner Springs | 33 15 | 116 45 | 3–4 | 1 | 30 | do | Felt by many | J. A. Ream. |
| | 6 26 | Calexico | 32 41 | 115 30 | 5 | 2 | 3<br>22 | do | Felt by several | H. M. Rouse. |
| | 6 30 | El Cajon | 32 48 | 116 58 | 4 | 1 | 5 | do | Awakened observer | E. F. Kessler. |
| 20 | 13 30 | San Diego | 32 40 | 117 10 | 5 | 1 | 1 | do | Felt by several | F. Matthews. |
| | 14 30 | San Diego | 32 40 | 117 10 | 4 | 1 | 2 | do | do | H. F. Alciatore. |
| | | ILLINOIS. | | | | | | | | |
| 1 | 15 00 | Mount Vernon | 38 20 | 89 00 | 5 | 2 | 30 | Rattling | Felt by many | H. B. Setzekorn. |
| | 15 15 | McLeansboro | 38 07 | 88 33 | 2 | 1 | | Faint | Felt by several | |
| | 15 30 | Du Quoin | | | 3 | | | None | do | G. H. Knetzger. |
| | 17 00 | McLeansboro | 38 07 | 88 33 | 2 | 1 | | | do | |
| | | MISSOURI. | | | | | | | | |
| 1 | 15 15 | Columbia | 38 55 | 92 15 | 4 | 1 | 30 | None | Felt by several | Preston Shearer. |
| | | Columbia | 38 55 | 92 15 | 5 | 2 | 30 | do | do | W. B. Shearer. |
| | 15 17 | Columbia | 38 55 | 92 15 | 3 | | 2–3 | do | Felt by one | O. M. Stewart. |
| | 15 18 | Warrenton | 38 50 | 91 10 | 3 | 1 | Short | Rattling | Felt by many | J. H. Frick. |
| | | NEW HAMPSHIRE. | | | | | | | | |
| 23 | 8 *ca* | Concord | 43 10 | 71 30 | 3 | 2 | Few | Rumbling | Distinct jar | E. C. Vose. |

TABLE 2.—*Instrumental Reports, May, 1920.*

[For significance of symbols and abbreviations, and for a description of stations and instruments, see the REVIEW for January, 1920, pp. 62–63.]

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | | ALASKA. *U. S. C. and G. S. Magnetic Observatory, Sitka.* | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | μ | μ | *Km.* | |
| May 7 | ..... | $e_E$ | 21 54 18 | ..... | ..... | ..... | ..... | |
| | | $e_N$ | 21 54 19 | ..... | ..... | ..... | ..... | |
| | | $eL_E$ | 22 09 30 | ..... | ..... | ..... | ..... | |
| | | $eL_N$ | 22 07 25 | 26 | ..... | ..... | ..... | |
| | | $M_E$ | 22 13 22 | 24 | 60 | ..... | ..... | |
| | | $M_N$ | 22 13 00 | ..... | ..... | 40 | ..... | |
| | | $C_E$ | 22 18 .. | 19 | ..... | ..... | ..... | |
| | | $C_N$ | 22 14 .. | ..... | ..... | ..... | ..... | |
| | | $F_E$ | 22 53 .. | ..... | ..... | ..... | ..... | |
| | | $F_N$ | 22 27 .. | ..... | ..... | ..... | ..... | |
| 13 | ..... | $eL_E$ | 2 28 21 | ..... | ..... | ..... | ..... | Nothing on N. |
| | | $M_E$ | 2 33 .. | 21 | 10 | ..... | ..... | |
| | | $F_E$ | 2 53 .. | ..... | ..... | ..... | ..... | |
| | | ARIZONA. *U. S. C. and G. S. Magnetic Observatory, Tucson.* | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | μ | μ | *Km.* | |
| May 7 | ..... | $L_E$ | 22 14 43 | 38 | ..... | ..... | ..... | N not in operation. |
| | | $M_E$ | 22 16 17 | 29 | 30 | ..... | ..... | |
| | | $C_E$ | 22 29 .. | 17 | ..... | ..... | ..... | |
| | | $F_E$ | 22 49 .. | 15 | ..... | ..... | ..... | |
| 13 | ..... | $L_E$ | 2 36 30 | 35 | ..... | ..... | ..... | Nothing on N. |
| | | $M_E$ | 2 41 .. | 20 | 10 | ..... | ..... | |
| | | $C_E$ | 2 56 .. | 16 | ..... | ..... | ..... | |
| | | $F_E$ | 3 21 .. | ..... | ..... | ..... | ..... | |
| 20 | ..... | $e_E$ | 7 49 50 | ..... | ..... | ..... | ..... | Do. |
| | | $L_E$ | 8 06 54 | 34 | ..... | ..... | ..... | |
| | | $M_E$ | 8 09 .. | 26 | 20 | ..... | ..... | |
| | | $C_E$ | 8 17 .. | 19 | ..... | ..... | ..... | |
| | | $F_E$ | 8 34 .. | 16 | ..... | ..... | ..... | |
| 30 | ..... | $P_E$ | 20 51 40 | ..... | ..... | ..... | ..... | Probably local. |
| | | $P_N$ | 20 51 26 | ..... | ..... | ..... | ..... | |
| | | $L_E$ | 20 51 56 | ..... | ..... | ..... | ..... | |
| | | $L_N$ | 20 51 57 | ..... | ..... | ..... | ..... | |
| | | $M_E$ | 20 52 25 | 9 | 50 | ..... | ..... | |
| | | $M_N$ | 20 52 35 | 8 | ..... | 30 | ..... | |
| | | C | 20 54 .. | ..... | ..... | ..... | ..... | |
| | | $F_E$ | 20 58 .. | 8 | ..... | ..... | ..... | |
| | | $F_N$ | 21 00 .. | ..... | ..... | ..... | ..... | |
| 30 | ..... | $P_E$ | 21 13 18 | ..... | ..... | ..... | ..... | Apparently a slight local shock. |
| | | $P_N$ | 21 13 19 | ..... | ..... | ..... | ..... | |
| | | $M_E$ | 21 14 50 | ..... | 10 | ..... | ..... | |
| | | F | 21 18 .. | ..... | ..... | ..... | ..... | |
| | | DISTRICT OF COLUMBIA. *Georgetown University, Washington.* | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | μ | μ | *Km.* | |
| May 7 | ..... | $e_E$ | 21 59 .. | ..... | ..... | ..... | ..... | Micros. No distinct M. |
| | | $e_N$ | 21 59 .. | ..... | ..... | ..... | ..... | |
| | | $eL_E$? | 22 03 36 | ..... | ..... | ..... | ..... | |
| | | $eL_N$? | 22 03 24 | ..... | ..... | ..... | ..... | |
| | | $L_N$ | 22 14 06 | 22 | ..... | ..... | ..... | |
| | | $L_N$ | 22 27 30 | 16 | ..... | ..... | ..... | |
| | | $L_E$ | 22 28 22 | 16 | ..... | ..... | ..... | |
| | | F | 23 45 .. | ..... | ..... | ..... | ..... | |
| 13 | ..... | $eP_E$? | 2 10 .. | ..... | ..... | ..... | ..... | Entire record doubtful. |
| | | $eP_N$? | 2 10 .. | ..... | ..... | ..... | ..... | |
| | | $S_E$? | 2 20 04 | ..... | ..... | ..... | ..... | |
| | | $S_N$? | 2 20 05 | ..... | ..... | ..... | ..... | |
| | | $eL_N$? | 2 47 00 | ..... | ..... | ..... | ..... | |
| | | $L_E$ | 2 51 .. | 27 | ..... | ..... | ..... | |
| | | $L_N$ | 2 50 .. | 29 | ..... | ..... | ..... | |
| | | F | 4 *ca.* | ..... | ..... | ..... | ..... | |
| | | VERTICAL. | | | | | | |
| 13 | ..... | $e_Z$ | 2 09 16 | ..... | ..... | ..... | ..... | |
| | | $L_Z$ | 2 50 23 | 30 | ..... | ..... | ..... | |
| | | $F_Z$ | 4 10 .. | ..... | ..... | ..... | ..... | |
| 20 | ..... | $L_E$ | 8 22 .. | 30 | ..... | ..... | ..... | Micros. |
| | | $L_N$ | 8 26 .. | 22 | ..... | ..... | ..... | |
| | | F | 8 52 .. | ..... | ..... | ..... | ..... | |
| 30 | ..... | $e_E$? | 21 04 19 | ..... | ..... | ..... | ..... | Do. |
| | | $e_N$? | 21 04 19 | ..... | ..... | ..... | ..... | |
| | | $eL_N$ | 21 06 19 | ..... | ..... | ..... | ..... | |
| | | F | 21 14 .. | ..... | ..... | ..... | ..... | |
| | | DISTRICT OF COLUMBIA. *U. S. Weather Bureau, Washington.* | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | *a* | *a* | *Km.* | |
| May 7 | ..... | eP | 6 02 06 | ..... | ..... | ..... | 8,850 | All amplitudes very small. |
| | | S | 6 12 09 | ..... | ..... | ..... | ..... | |
| | | eL? | 6 29 30 | ..... | ..... | ..... | ..... | |
| | | L | 6 45 30 | 24 | ..... | ..... | ..... | |
| | | L | 7 06 .. | 20 | ..... | ..... | ..... | |
| | | F | 7 20 *ca.* | ..... | ..... | ..... | ..... | |
| 7 | ..... | eP | 21 51 54 | ..... | ..... | ..... | ..... | |
| | | S | 22 01? .. | ..... | ..... | ..... | ..... | |
| | | L? | 22 09 .. | ..... | ..... | ..... | ..... | |
| | | L | 22 32 .. | 24 | ..... | ..... | ..... | |
| | | L | 22 45 .. | 20 | ..... | ..... | ..... | |
| | | L | 22 50 .. | 16 | ..... | ..... | ..... | |
| | | F | 24 *ca.* | ..... | ..... | ..... | ..... | |

TABLE 2.—*Instrumental Reports, May, 1920*—Continued.

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| **DISTRICT OF COLUMBIA.** *U. S. Weather Bureau, Washington*—Continued. | | | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 8 | ..... | e..... | 21 23 .. | ..... | ..... | ..... | ..... | |
| | | F..... | 21 42 .. | ..... | ..... | ..... | ..... | |
| 8 | ..... | e..... | 23 41 .. | ..... | ..... | ..... | ..... | |
| | | F..... | 23 52 .. | ..... | ..... | ..... | ..... | |
| 10 | ..... | P..... | 19 11 36 | ..... | ..... | ..... | ..... | Other phases indistinguishable. |
| | | F..... | 19 40 *ca.* | ..... | ..... | ..... | ..... | |
| 13 | ..... | eP..... | 2 09 50 | ..... | ..... | ..... | ..... | |
| | | eL..... | 2 44 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 2 50 .. | 24 | ..... | ..... | ..... | |
| | | L..... | 3 02 .. | 20 | ..... | ..... | ..... | |
| | | F..... | 3 30 *ca.* | ..... | ..... | ..... | ..... | |
| 20 | ..... | eL..... | 8 16 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 8 21 .. | 40 | ..... | ..... | ..... | |
| | | L..... | 8 24 .. | 24 | ..... | ..... | ..... | |
| | | L..... | 8 26 .. | 20 | ..... | ..... | ..... | |
| | | F..... | 8 45 *ca.* | ..... | ..... | ..... | ..... | |
| 26 | ..... | eL..... | 13 16 30 | ..... | ..... | ..... | ..... | |
| | | F..... | 13 45 *ca.* | ..... | ..... | ..... | ..... | |
| 30 | ..... | e..... | 21 04 25 | ..... | ..... | ..... | ..... | |
| | | F..... | 21 10 .. | ..... | ..... | ..... | ..... | |
| **ILLINOIS.** *U. S. Weather Bureau, Chicago.* | | | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 2 | ..... | eL..... | 9 16 30 | ..... | ..... | ..... | ..... | Possibly not seismic. |
| | | L..... | 9 28 30 | 22 | ..... | ..... | ..... | |
| | | L..... | 9 30 30 | 18 | ..... | ..... | ..... | |
| | | F..... | 9 50 *ca.* | ..... | ..... | ..... | ..... | |
| 7 | ..... | iP..... | 6 01 20 | ..... | ..... | ..... | 8,700 | |
| | | S..... | 6 11 14 | ..... | ..... | ..... | ..... | |
| | | L..... | 6 33 .. | 50 | ..... | ..... | ..... | |
| | | L..... | 6 40 .. | 30 | ..... | ..... | ..... | |
| | | L..... | 6 45 .. | 24 | ..... | ..... | ..... | |
| | | L..... | 6 55 .. | 18 | ..... | ..... | ..... | |
| | | L..... | 7 11 .. | 16 | ..... | ..... | ..... | |
| | | F..... | 8 20 *ca.* | ..... | ..... | ..... | ..... | |
| 7 | ..... | P..... | 21 50 42 | ..... | ..... | ..... | 8,450 | |
| | | S..... | 22 00 25 | ..... | ..... | ..... | ..... | |
| | | L..... | 22 07 57 | ..... | ..... | ..... | ..... | |
| | | L..... | 22 12 35 | 22 | ..... | ..... | ..... | |
| | | L..... | 22 26 .. | 30 | ..... | ..... | ..... | |
| | | L..... | 22 30 .. | 24 | ..... | ..... | ..... | |
| | | L..... | 22 35 .. | 18 | ..... | ..... | ..... | |
| 8 | ..... | F..... | 1 40 .. | ..... | ..... | ..... | ..... | |
| 8 | ..... | P?..... | 20 40 54 | ..... | ..... | ..... | ..... | |
| | | S..... | 20 50 53 | ..... | ..... | ..... | ..... | |
| | | F..... | 21 07 *ca.* | ..... | ..... | ..... | ..... | |
| 8 | ..... | P?..... | 21 17 *ca.* | ..... | ..... | ..... | ..... | |
| | | S..... | 21 27 45 | ..... | ..... | ..... | ..... | |
| | | F..... | 22 *ca.* .. | ..... | ..... | ..... | ..... | |
| 8 | ..... | P?..... | 23 26 06 | ..... | ..... | ..... | ..... | |
| | | S..... | 23 36 30 | ..... | ..... | ..... | ..... | |
| | | F..... | 24 *ca.* .. | ..... | ..... | ..... | ..... | |
| 9 | ..... | P?..... | 8 18 45 | ..... | ..... | ..... | ..... | |
| | | S?..... | 8 28 40 | ..... | ..... | ..... | ..... | |
| | | eL..... | 8 55 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 8 57 .. | 24 | ..... | ..... | ..... | |
| | | F..... | 9 30 *ca.* | ..... | ..... | ..... | ..... | |
| 10 | ..... | P..... | 19 11 24 | ..... | ..... | ..... | 10,000 | |
| | | S..... | 19 22 12 | ..... | ..... | ..... | ..... | |
| | | eL..... | 19 51 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 19 57 .. | 22 | ..... | ..... | ..... | |
| | | F..... | 21 30 *ca* | ..... | ..... | ..... | ..... | |
| 13 | ..... | P..... | 2 09 08 | ..... | ..... | ..... | 8,300? | |
| | | S?..... | 2 18 40 | ..... | ..... | ..... | ..... | |
| | | eL..... | 2 41 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 2 50 .. | 22 | ..... | ..... | ..... | |
| | | L..... | 3 20 .. | 16 | ..... | ..... | ..... | |
| | | F..... | 4 50 *ca* | ..... | ..... | ..... | ..... | |
| 20 | ..... | P..... | 7 45 02 | ..... | ..... | ..... | 8,200 | |
| | | S..... | 7 54 30 | ..... | ..... | ..... | ..... | |
| | | L..... | 8 18 .. | 35 | ..... | ..... | ..... | |
| | | L..... | 8 22 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 8 27 .. | 18 | ..... | ..... | ..... | |
| | | L..... | 8 42 .. | 15 | ..... | ..... | ..... | |
| | | F..... | 10 10 *ca* | ..... | ..... | ..... | ..... | |
| 22 | ..... | eL..... | 17 59 30 | ..... | ..... | ..... | ..... | |
| | | L..... | 18 02 .. | 22 | ..... | ..... | ..... | |
| | | F..... | 18 15 *ca* | ..... | ..... | ..... | ..... | |
| 26 | ..... | P?..... | 12 46 00 | ..... | ..... | ..... | ..... | |
| | | S?..... | 12 53 16 | ..... | ..... | ..... | ..... | |
| | | L..... | 13 12 15 | 18 | ..... | ..... | ..... | |
| | | L..... | 13 20 .. | 16 | ..... | ..... | ..... | |
| | | F..... | 14 30 *ca* | ..... | ..... | ..... | ..... | |

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| **ILLINOIS.** *U. S. Weather Bureau, Chicago*—Continued. | | | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 27 | ..... | P?..... | 6 09 30 | ..... | ..... | ..... | ..... | Amplitudes very small. |
| | | S?..... | 6 19 37 | ..... | ..... | ..... | ..... | |
| | | F..... | 7 10 *ca* | ..... | ..... | ..... | ..... | |
| 30 | ..... | P..... | 20 58 14 | ..... | ..... | ..... | 1,700 | |
| | | S..... | 21 01 10 | ..... | ..... | ..... | ..... | |
| | | L..... | 21 02 00 | ..... | ..... | ..... | ..... | |
| | | F..... | 21 30 *ca* | ..... | ..... | ..... | ..... | |
| **MARYLAND.** *U. S. C. and G. S. Magnetic Observatory, Cheltenham.* | | | | | | | | |
| 1920 | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 7 | ..... | $e_E$..... | 21 53 48 | ..... | ..... | ..... | ..... | |
| | | $e_N$..... | 22 14 00 | ..... | ..... | ..... | ..... | |
| | | $eL_E$... | 22 31 20 | ..... | ..... | ..... | ..... | |
| | | $eL_N$... | 22 29 48 | 14 | ..... | ..... | ..... | |
| | | $M_E$.... | 22 41 45 | 18 | 40 | 10 | ..... | |
| | | $C_E$.... | 23 06 .. | 16 | ..... | ..... | ..... | |
| | | $C_N$.... | 22 48 .. | ..... | ..... | ..... | ..... | |
| | | $F_E$.... | 23 59 .. | ..... | ..... | ..... | ..... | |
| | | $F_N$.... | 23 19 .. | ..... | ..... | ..... | ..... | |
| 13 | ..... | $eL_E$... | 3 01 40 | ..... | ..... | ..... | ..... | |
| | | $eL_N$... | 2 55 12 | ..... | ..... | ..... | ..... | |
| | | $M_E$.... | 3 04 00 | 19 | ..... | ..... | ..... | |
| | | $M_N$.... | 3 03 12 | 20 | ..... | 10 | ..... | |
| | | $F_E$.... | 3 13 .. | ..... | ..... | ..... | ..... | |
| | | $F_N$.... | 3 12 .. | 18 | ..... | ..... | ..... | |
| 20 | ..... | $eL_E$... | 8 22 10 | 20 | ..... | ..... | ..... | Nothing on N. |
| | | $F_E$.... | 8 35 .. | ..... | ..... | ..... | ..... | |
| 30 | ..... | $eP_E$... | 21 05 16 | ..... | ..... | ..... | ..... | Apparently not far off, but shocks were recorded at about the same time at Cambridge and Tucson. |
| | | $P_N$.... | 21 04 48 | ..... | ..... | ..... | ..... | |
| | | $eL_E$... | 21 07 10 | 8 | ..... | ..... | ..... | |
| | | $M_N$.... | 21 06 22 | ..... | ..... | 20 | ..... | |
| | | $F_E$.... | 21 10 .. | ..... | ..... | ..... | ..... | |
| | | $F_N$.... | 21 09 .. | ..... | ..... | ..... | ..... | |
| **MASSACHUSETTS.** *Harvard University, Cambridge.* | | | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 7 | ..... | O?.... | 21 35 *ca* | ..... | ..... | ..... | 12,300 | Distance by L–S; 110.°7 of arc. |
| | | $eP_N$?.. | 21 51 45 | ..... | ..... | ..... | ..... | |
| | | $eP_E$... | 21 52 36 | 4 | ..... | ..... | ..... | |
| | | $S_N$?... | 22 03 52 | 10 | ..... | ..... | ..... | |
| | | $i_E$..... | 22 09 56 | 20 | ..... | ..... | ..... | |
| | | $eL_E$... | 22 30 26 | 48 | ..... | ..... | ..... | |
| | | $eL_N$... | 22 30 30 | 40 | ..... | ..... | ..... | |
| | | $M_E$.... | 22 45 11 | 17 | *1,500 | ..... | ..... | |
| 8 | ..... | $F_E$.... | 0 16 *ca* | ..... | ..... | ..... | ..... | |
| 8 | ..... | O..... | 21 *postea* | ..... | ..... | ..... | ..... | N record microseismic; times approximate. |
| | | e?..... | 21 32 42 | 6 & 8 | ..... | ..... | ..... | |
| | | $L_E$.... | 21 34 12 | 12 | ..... | ..... | ..... | |
| | | $L_N$.... | 21 35 00 | 10 | ..... | ..... | ..... | |
| | | $L_E$.... | 21 36 54 | 15 | ..... | ..... | ..... | |
| | | F..... | 22 *ca* | ..... | ..... | ..... | ..... | |
| 12 | ..... | O?.... | 1 55 34 | ..... | ..... | ..... | 11,530 | 103°.7 of arc; eL–S gives 11380 km.; 1–55–47 with VL 228 km. |
| | | $eP_N$... | 2 09 48 | ..... | ..... | ..... | ..... | |
| | | $eP_E$... | 2 09 58 | ..... | ..... | ..... | ..... | |
| | | $iP_E$... | 2 10 17 | 4 | ..... | ..... | ..... | |
| | | $iP_N$... | 2 10 29 | 6 | ..... | ..... | ..... | |
| | | $S_E$?... | 2 21 50 | 10 | ..... | ..... | ..... | |
| | | $eL_{NE}$.. | 2 45 42 | 40 | ..... | ..... | ..... | |
| | | $M_N$.... | 2 52 22 | 22 | ..... | *1,500 | ..... | |
| | | $F_E$.... | 4 21 *ca* | ..... | ..... | ..... | ..... | |
| 17 | ..... | $eL_N$... | 20 56 09 | 10 | ..... | ..... | ..... | Possibly only micros; not well shown on E–W. |
| | | F..... | 20 57 41 | ..... | ..... | ..... | ..... | |
| 20 | ..... | O..... | 7 *postea* | ..... | ..... | ..... | ..... | P and S too faint for diagnosis; both components damped 1½/1 by small magnets. |
| | | $e_N$?... | 7 30 45 | ..... | ..... | ..... | ..... | |
| | | $e_N$..... | 7 32 35 | 12 | ..... | ..... | ..... | |
| | | $e_N$..... | 7 45 57 | 4 | ..... | ..... | ..... | |
| | | $e_E$..... | 7 46 44 | ..... | ..... | ..... | ..... | Strong; at great distance. eS? at 7–46–44. |
| | | $e_E$..... | 7 59 34 | 8 | ..... | ..... | ..... | |
| | | $e_E$..... | 8 03 40 | 12 | ..... | ..... | ..... | |
| | | $eL_N$... | 8 16 42 | 60 | ..... | ..... | ..... | $L_{R1}$–eL is 61.3 m., *ca;* distance 13500 *ca.* |
| | | $L_N$.... | 8 19 00 | 40 | ..... | ..... | ..... | |
| | | $L_N$.... | 8 21 18 | 30 | ..... | ..... | ..... | |
| | | $L_E$.... | 8 22 35 | 40 | ..... | ..... | ..... | |
| | | $L_E$.... | 8 27 24 | 28 | ..... | ..... | ..... | |
| | | $L_N$.... | 8 27 54 | 20 | ..... | ..... | ..... | |
| | | $L_E$.... | 8 31 00 | 20 | ..... | ..... | ..... | |
| | | $L_{RE}$... | 9 18 22 | 28 | ..... | ..... | ..... | Possibly Me set in at 9–25. |
| | | $L_E$.... | 9 38 66 | 20 | ..... | ..... | ..... | |
| | | $F_N$.... | 9 45 24 | ..... | ..... | ..... | ..... | |
| 26 | ..... | O?.... | 12 28 09 | ..... | ..... | ..... | 8,900? | Dist. from $S_{R1}$–S; $eL_E$ suppressed until M sets in. |
| | | $S_E$..... | 12 50 21 | 8 | ..... | ..... | ..... | |
| | | $S_{RIE}$ .. | 12 56 15 | 12 | ..... | ..... | ..... | |
| | | $L_E$.... | 13 19 05 | 16 | ..... | ..... | ..... | eL should read 13–17 *ca.* |
| | | $M_E$?... | 13 20 10 | 18 | ..... | ..... | ..... | |
| | | | to 24 25 | ..... | ..... | ..... | ..... | No distinct record on N comp., damped 1½/1 by magnet. |
| | | $L_E$.... | 13 29 56 | 15 | ..... | ..... | ..... | |
| | | $F_E$.... | 14 *ca* | ..... | ..... | ..... | ..... | |

*Trace amplitude.

TABLE 2.—*Instrumental Reports, May, 1920*—Continued.

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| **MASSACHUSETTS.** *Harvard University, Cambridge*—Continued. | | | | | | | | |
| 1920. May 30 | ..... | O?.... | *H. m. s.* 20 *postea* | *Sec.* ..... | μ ..... | μ ..... | *Km.* ..... | P and S ill defined and masked on N record by pulsations of various periods. Dist. 3740 *ca.* which would put O at 20h 50m. |
| | | $eP_N$?.. | 20 57 00 | ..... | ..... | ..... | ..... | |
| | | $eP_{RE}$? | 20 58 21 | 2 | ..... | ..... | ..... | |
| | | $e_E$..... | 21 02 04 | 6 | ..... | ..... | ..... | |
| | | $e_E$..... | 21 02 54 | ..... | ..... | ..... | ..... | |
| | | $eL_N$... | 21 06 25 | 20 | ..... | ..... | ..... | |
| | | $eL_E$... | 21 07 26 | 16 | ..... | ..... | ..... | |
| | | $M_N$.... | 21 07 21 | 15 | ..... | ..... | ..... | |
| | | $M_N$.... | 21 07 39 | 15 | ..... | ..... | ..... | |
| | | $L_E$?... | 21 10 40 to 12 26 | 8 ..... | ..... | ..... | ..... | |
| | | $L_E$.... | 21 14 08 | 8 | ..... | ..... | ..... | |
| | | F..... | 21 21 *ca* | ..... | ..... | ..... | ..... | |
| **NEW YORK.** *Cornell University, Ithaca.* | | | | | | | | |
| 1920. May 7 | ..... | L..... | *H. m. s.* 22 27 30 | *Sec.* 20 | μ ..... | μ ..... | *Km.* ..... | |
| | | F..... | 23 44 — | ..... | ..... | ..... | ..... | |
| 13 | ..... | $eS_E$.... | 2 26 40 | 15 | ..... | ..... | ..... | |
| | | L..... | 2 48 35 | 38 | ..... | ..... | ..... | |
| | | F..... | 3 30 — | ..... | ..... | ..... | ..... | |
| 20 | ..... | $L_E$.... | 8 22 10 | 35 | ..... | ..... | ..... | |
| | | F..... | 8 54 — | ..... | ..... | ..... | ..... | |
| 26 | ..... | $L_E$.... | 13 16 37 | 20 | ..... | ..... | ..... | |
| | | F..... | 13 28 — | ..... | ..... | ..... | ..... | |
| 30 | ..... | $e_N$..... | 21 04 13 | 3 | ..... | ..... | ..... | |
| | | $e_E$..... | 21 06 27 | 8 | ..... | ..... | ..... | |
| | | F..... | ..... | ..... | ..... | ..... | ..... | Lost in changing sheets after 21:15. |
| **VERMONT.** *U. S. Weather Bureau, Northfield.* | | | | | | | | |
| 1920. May 7 | ..... | eL..... | *H. m. s.* 22 31 .. | *Sec.* ..... | μ ..... | μ ..... | *Km.* ..... | |
| | | F..... | 22 50 .. | ..... | ..... | ..... | ..... | |
| 13 | ..... | eL..... | 2 55 .. | ..... | ..... | ..... | ..... | |
| | | L..... | 2 58 .. | 20 | ..... | ..... | ..... | |
| | | F..... | 3 07 *ca* | ..... | ..... | ..... | ..... | |
| **CANADA.** *Dominion Observatory, Ottawa.* | | | | | | | | |
| 1920. May 7 | ..... | eL..... | *H. m. s.* 6 35 to 7 20 .. | *Sec.* 24 18 | μ ..... ..... | μ ..... ..... | *Km.* ..... ..... | |
| 7 | ..... | e..... | 21 51 36 | 4 | ..... | ..... | ..... | |
| | | eL..... | 22 22 .. | 40 | ..... | ..... | ..... | |
| | | L..... | 22 35 .. | 28 | ..... | ..... | ..... | |
| | | L..... | 22 46 .. | 18 | ..... | ..... | ..... | |
| | | L..... | 23 00 .. | 15 | ..... | ..... | ..... | |
| | | F..... | 23 30 .. | ..... | ..... | ..... | ..... | |
| 8 | ..... | e..... | 21 28 to 21 45 .. | ..... | ..... | ..... | ..... | Very faint; may not be seismic. |
| 8 | ..... | e..... | 23 36 to 23 55 .. | ..... | ..... | ..... | ..... | Do. |
| 26 | ..... | e..... | 13 11 *to* 13 30 .. | ..... | ..... | ..... | ..... | L waves on EW very small but regular and sinusoidal. Waves on NS very irregular. |
| | | $L_E$.... | 13 20 *to* 14 00 .. | ..... | ..... | ..... | ..... | |
| **CANADA.** *Dominion Meteorological Service, Toronto.* | | | | | | | | |
| 1920. May 7 | ..... | e..... | *H. m. s.* 6 01 30 | *Sec.* ..... | μ ..... | μ ..... | *Km.* ..... | |
| | | L..... | 6 50 30 | ..... | ..... | ..... | ..... | |
| | | L..... | 6 53 48 | ..... | ..... | ..... | ..... | |
| | | eL..... | 7 58 42 | ..... | ..... | ..... | ..... | |
| | | M..... | 7 08 24 | ..... | *300 | ..... | ..... | |
| | | F..... | 7?44 42 | ..... | ..... | ..... | ..... | |
| 7 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Record of quake lost. |
| 8 | ..... | L..... | 21 33 48 | ..... | ..... | ..... | ..... | |
| | | M..... | 21 35 00 | ..... | *100 | ..... | ..... | |
| | | F..... | 21 47 54 | ..... | ..... | ..... | ..... | |
| 8 | ..... | L..... | 23 20 54 | ..... | ..... | ..... | ..... | |
| | | L..... | 23 35 54 | ..... | *50 | ..... | ..... | |

*Trace amplitude.

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| **CANADA.** *Dominion Meteorological Service, Toronto*—Continued. | | | | | | | | |
| 1920. May 9 | ..... | e..... | *H. m. s.* 8 27 30 | *Sec.* ..... | μ ..... | μ ..... | *Km.* ..... | |
| | | L..... | 8 31 06 | ..... | *100 | ..... | ..... | |
| | | F..... | ..... | ..... | ..... | ..... | ..... | |
| 10 | ..... | P..... | 19?11 24 | ..... | ..... | ..... | ..... | |
| | | S..... | 19?18 18 | ..... | ..... | ..... | ..... | |
| | | L..... | 19 22 48 | ..... | ..... | ..... | ..... | |
| | | eL..... | 19 28 54 | ..... | ..... | ..... | ..... | |
| | | M..... | 19 32 00 | ..... | *300 | ..... | ..... | |
| | | L..... | 19 49 48 | ..... | ..... | ..... | ..... | |
| 10 | ..... | eL..... | 20 03 36 | ..... | ..... | ..... | ..... | |
| | | M..... | 20 05 36 | ..... | *400 | ..... | ..... | |
| | | eL..... | 20 16 54 | ..... | ..... | ..... | ..... | |
| | | M..... | 20 20 00 | ..... | *500 | ..... | ..... | |
| | | F..... | 20 36 24 | ..... | ..... | ..... | ..... | |
| 12 | ..... | S?..... | 2 20 36 | ..... | ..... | ..... | ..... | Time for first phase doubtful. |
| | | L or S | 2 26 54 | ..... | ..... | ..... | ..... | |
| | | L..... | 2 44 54 | ..... | ..... | ..... | ..... | |
| | | iL..... | 2 55 42 | ..... | ..... | ..... | ..... | |
| | | M..... | 3 09 18 | ..... | *2,800 | ..... | ..... | |
| | | $L_{REP}$.. | 3 58 42 | ..... | ..... | ..... | ..... | |
| | | M..... | 4 02 06 | ..... | *400 | ..... | ..... | |
| 14 | ..... | L..... | 18?31 18 | ..... | ..... | ..... | ..... | |
| | | F..... | ..... | ..... | *50 | ..... | ..... | |
| 19 | ..... | L..... | 13 39 24 | ..... | ..... | ..... | ..... | |
| | | L..... | 13 52 30 | ..... | *100 | ..... | ..... | |
| 20 | ..... | e..... | 7?31 00 | ..... | ..... | ..... | ..... | |
| | | S?..... | 7 56 24 | ..... | ..... | ..... | ..... | |
| | | L..... | 8 02 18 | ..... | ..... | ..... | ..... | |
| | | L..... | 8 27 42 | ..... | ..... | ..... | ..... | |
| | | eL..... | 8 37 54 | ..... | ..... | ..... | ..... | |
| | | M..... | 8 40 00 | ..... | *500 | ..... | ..... | |
| | | $L_{REP}$.. | 9 35 24 | ..... | ..... | ..... | ..... | |
| | | L..... | 9 38 12 | ..... | ..... | ..... | ..... | |
| | | F..... | 9 58 00 | ..... | ..... | ..... | ..... | |
| 21 | ..... | L..... | 17 36 12 | ..... | ..... | ..... | ..... | May not be seism. |
| | | L..... | 17 51 36 | ..... | *200 | ..... | ..... | |
| 22 | ..... | eL..... | 17 13 06 | ..... | ..... | ..... | ..... | |
| | | M..... | 17 15 18 | ..... | *200 | ..... | ..... | |
| | | F..... | 17 20 18 | ..... | ..... | ..... | ..... | |
| 26 | ..... | e..... | 12 51 18 | ..... | ..... | ..... | ..... | |
| | | e..... | 13 03 12 | ..... | ..... | ..... | ..... | |
| | | eL..... | 13 17 36 | ..... | ..... | ..... | ..... | |
| | | M..... | 13 21 36 | ..... | *300 | ..... | ..... | |
| | | F..... | 13?48 06 | ..... | ..... | ..... | ..... | Thickening. |
| 30 | ..... | L..... | 21 04 18 | ..... | ..... | ..... | ..... | Micros going on. |
| | | L..... | 21?18 06 | ..... | *100 | ..... | ..... | |
| **CANADA.** *Dominion Meteorological Service, Victoria.* | | | | | | | | |
| 1920 May 7 | ..... | P?..... | *H. m. s.* 5 56 09 | *Sec.* ..... | μ ..... | μ ..... | *Km.* ..... | |
| | | S..... | 6 05 01 | ..... | ..... | ..... | ..... | |
| | | L..... | 6 17 18 | ..... | ..... | ..... | ..... | |
| | | M..... | 6 32 03 | ..... | *500 | ..... | 7,440 | |
| | | F..... | 8 18 47 | ..... | ..... | ..... | ..... | |
| 7 | ..... | P..... | 21 53 43 | ..... | ..... | ..... | 5,230 | Very clear record. |
| | | S..... | 22 00 37 | ..... | ..... | ..... | ..... | |
| | | L..... | 22 10 57 | ..... | ..... | ..... | ..... | |
| | | M..... | 22 18 49 | ..... | *300 | ..... | ..... | |
| | | $L_{REP}$.. | 23 51 07 | ..... | ..... | ..... | ..... | |
| | | L..... | 23 56 37 | ..... | ..... | ..... | ..... | |
| 8 | ..... | M..... | 0 00 37 | ..... | *400 | ..... | ..... | |
| | | F..... | 0 47 49 | ..... | ..... | ..... | ..... | |
| 8 | ..... | P..... | 21 06 33 | ..... | ..... | ..... | ..... | |
| | | M..... | 21 11 58 | ..... | *200 | ..... | ..... | |
| | | F..... | 21 23 16 | ..... | ..... | ..... | ..... | |
| 8 | ..... | P..... | 23 20 19 | ..... | ..... | ..... | ..... | May not be seismic. |
| | | M..... | 23 21 48 | ..... | *100 | ..... | ..... | |
| | | F..... | 23 25 14 | ..... | ..... | ..... | ..... | |
| 9 | ..... | P..... | 8 39 32 | ..... | ..... | ..... | ..... | |
| | | M..... | 8 44 56 | ..... | *200 | ..... | ..... | |
| | | F..... | 8 51 49 | ..... | ..... | ..... | ..... | |
| 10 | ..... | P..... | 19 12 05 | ..... | ..... | ..... | ..... | |
| | | S..... | 19 20 26 | ..... | ..... | ..... | ..... | |
| | | L..... | 19 32 14 | ..... | ..... | ..... | ..... | |
| | | eL..... | 19 41 04 | ..... | ..... | ..... | ..... | |
| | | M..... | 19 43 33 | ..... | *900 | ..... | 6,840 | |
| | | F..... | 21 13 33 | ..... | ..... | ..... | ..... | |
| 13 | ..... | P..... | 2 13 13 | ..... | ..... | ..... | ..... | |
| | | S..... | 2 19 07 | ..... | ..... | ..... | ..... | |
| | | L..... | 2 29 56 | ..... | ..... | ..... | ..... | |
| | | M..... | 2 37 18 | ..... | *3,000 | ..... | 4,120 | |
| | | $L_{REP}$.. | 4 09 50 | ..... | ..... | ..... | ..... | |
| | | F..... | 4 39 01 | ..... | ..... | ..... | ..... | |
| 14 | ..... | P..... | 18 23 51 | ..... | ..... | ..... | ..... | |
| | | M..... | 18 26 20 | ..... | *200 | ..... | ..... | |
| | | F..... | 18 38 44 | ..... | ..... | ..... | ..... | |
| 19 | ..... | P or L. | 13?33 51 | ..... | ..... | ..... | ..... | |
| | | M..... | 13 38 17 | ..... | *100 | ..... | ..... | |

* Trace amplitude

TABLE 2.—*Instrumental Reports, May, 1920*—Continued.

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| CANADA. *Dominion Meteorological Service, Victoria*—Continued. | | | | | | | | |
| 1920. | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| May 20 | ..... | P..... | 7 39 09 | ..... | ..... | ..... | 8,700 | May be near Guam. |
| | | S..... | 7 49 04 | ..... | ..... | ..... | ..... | |
| | | L..... | 8 01 57 | ..... | ..... | ..... | ..... | |
| | | M..... | 8 12 52 | ..... | *500 | ..... | ..... | |
| | | F..... | 10 21 13 | ..... | ..... | ..... | ..... | |
| 22 | ..... | L..... | 17 42 21 | ..... | ..... | ..... | ..... | |
| | | M..... | 17 48 48 | ..... | *500 | ..... | ..... | |
| | | F..... | 17 58 13 | ..... | ..... | ..... | ..... | |
| 26 | ..... | P or S. | 12 44 45 | ..... | ..... | ..... | ..... | |
| | | L..... | 12 57 04 | ..... | ..... | ..... | ..... | |
| | | M..... | 13 02 00 | ..... | *500 | ..... | ..... | |
| | | F..... | 13 26 55 | ..... | ..... | ..... | ..... | |
| 27 | ..... | M..... | 6?21 14 | ..... | *50 | ..... | ..... | May be due to light variations. |
| 30 | ..... | P..... | 20 58 53 | ..... | ..... | ..... | ..... | |
| | | L..... | 21 02 50 | ..... | ..... | ..... | ..... | |
| | | M..... | 21 04 48 | ..... | *400 | ..... | ..... | |
| | | F..... | ? | ..... | ..... | ..... | ..... | |

* Trace amplitude.

The following stations recorded no earthquakes during May, 1920:

ALABAMA. *Spring Hill College, Mobile.*
COLORADO. *Sacred Heart College, Denver.*

Reports for May, 1920, have not been received from the following stations:

HAWAII. *U. S. C. and G. S. Magnetic Observatory, Honolulu.*
KANSAS. *University of Kansas, Lawrence.*
MISSOURI. *St. Louis University, St. Louis.*
NEW YORK. *Canisius College, Buffalo; Fordham University, New York.*
CANAL ZONE. *Panama Canal, Balboa Heights.*
PORTO RICO. *U. S. C. and G. S. Magnetic Observatory, Vieques.*

For the reports of the stations at the University of California, Berkeley, Calif., and at the Lick Observatory, Mount Hamilton, Calif., see *Bulletin of the Seismographic Stations, University of California.* For the report of the University of Santa Clara station, see *Record of the Seismographic Stations, University of Santa Clara.*

## SEISMOLOGICAL DISPATCHES.[1]

*Mexico City, April 20, 1920.*

A severe earthquake was felt here at 2:30 o'clock yesterday afternoon. Telegrams from Orizaba and Jalaps stated that shocks were felt in those States and elsewhere in the State of Vera Cruz simultaneously.—*Associated Press.*

[1] Reported by the organization indicated and collected by the Seismological station, Georgetown University, Washington, D. C.

*St. Louis, Mo., May 1, 1920.*

An earthquake shock was felt in St. Louis this morning. Experts at Washington University stated the seismograph there recorded the shock as 200 miles from St. Louis.—*Associated Press.*

*Mount Vernon, Ill., May 1, 1920.*

Mount Vernon and the surrounding country was rocked twice this morning by an earthquake or explosion. The first shock, lasting about a quarter of a minute, was felt at 9:15 a. m., and the second about 10:09 a. m.—*Associated Press.*

*New York, N. Y., May 4, 1920.*

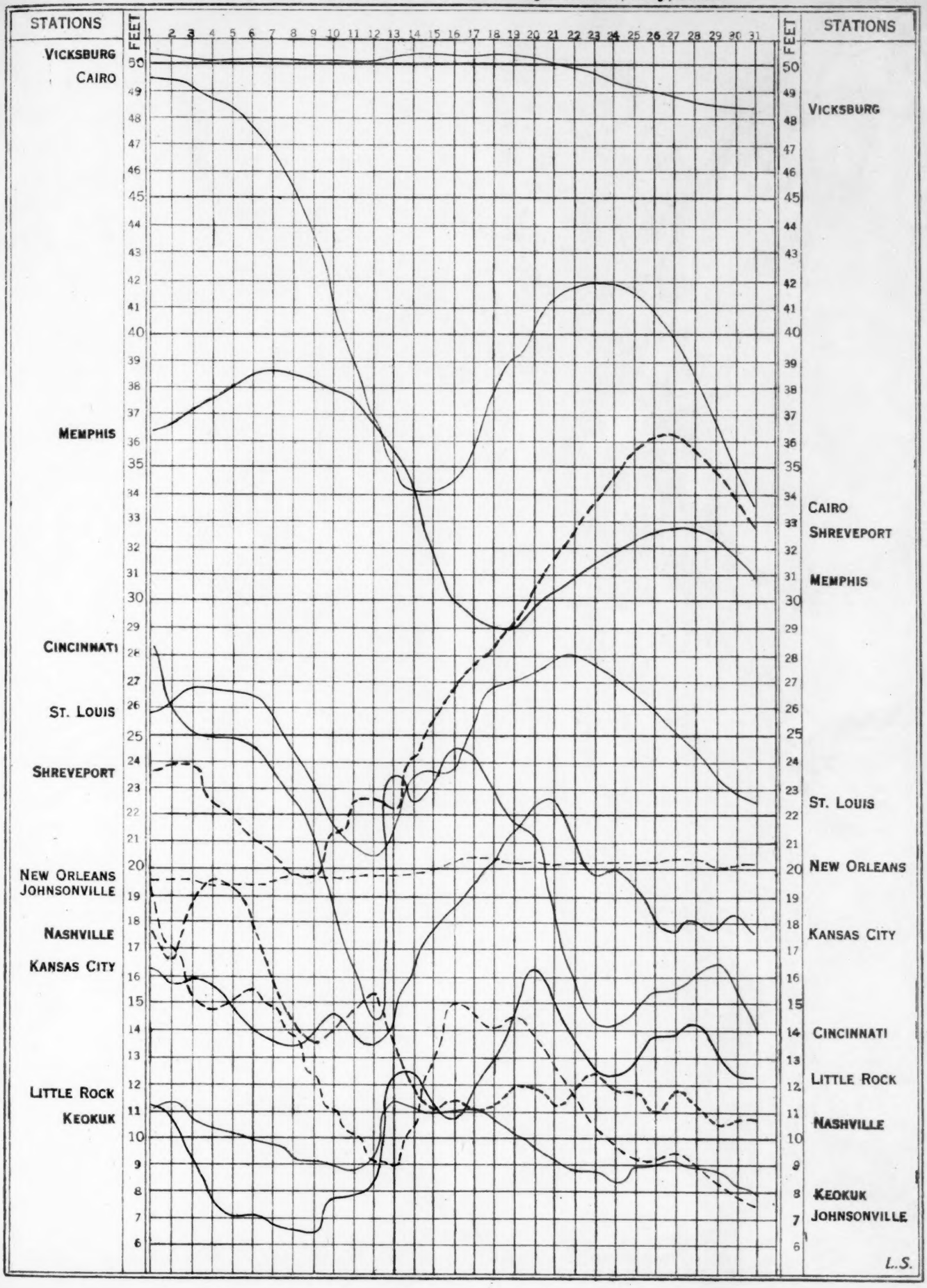
Indications that a volcanic eruption was taking place on the island of Old Providence in the Caribbean Sea were reported here to-day by the United Fruit Company steamer *Calamares.* A wireless message from the ship said that volumes of white smoke were observed ascending from one of its tallest peaks late yesterday afternoon.—*Associated Press.*

TABLE 3.—*Late reports, (Instrumental).*

| Date. | Character. | Phase. | Time. | Period T. | Amplitude. $A_E$ | Amplitude. $A_N$ | Distance. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| HAWAII. *U. S. C. and G. S. Magnetic Observatory, Honolulu.* | | | | | | | | |
| 1920 | | | *H. m. s.* | *Sec.* | $\mu$ | $\mu$ | *Km.* | |
| Apr. 2 | ..... | eP..... | 1 22 12 | 17 | ..... | ..... | ..... | Phases distinct but not consistent. |
| | | eS..... | 1 28 6 | 17 | ..... | ..... | ..... | |
| | | eL..... | 1 31 42 | ..... | ..... | ..... | ..... | |
| | | eL..... | 1 35 00 | ..... | ..... | ..... | ..... | |
| | | M..... | 1 38 24 | 17 | *800 | ..... | ..... | |
| | | C..... | 1 55 .. | ..... | ..... | ..... | ..... | |
| | | F..... | 2 32 .. | 18 | ..... | ..... | ..... | |
| 2 | ..... | P..... | 15 29 00 | 18 | ..... | ..... | ..... | |
| | | L..... | 15 45 24 | ..... | ..... | ..... | ..... | |
| | | M..... | 15 51 24 | 17 | *300 | ..... | ..... | |
| | | C..... | 15 58 .. | 17 | ..... | ..... | ..... | |
| | | F..... | 16 18 .. | ..... | ..... | ..... | ..... | |
| 6 | ..... | P..... | 19 11 36 | 16 | ..... | ..... | ..... | |
| | | iS..... | 19 18 36 | 17 | ..... | ..... | ..... | |
| | | L..... | 19 26 54 | ..... | ..... | ..... | ..... | |
| | | M..... | 19 39 12 | 17 | *700 | ..... | ..... | |
| | | C..... | 19 52 .. | 15 | ..... | ..... | ..... | |
| | | F..... | 20 31 .. | 16 | ..... | ..... | ..... | |
| 11 | ..... | P..... | 23 19 12 | 17 | ..... | ..... | ..... | |
| | | S..... | 23 23 00 | 15 | ..... | ..... | ..... | |
| | | eL..... | 23 28 24 | ..... | ..... | ..... | ..... | |
| | | M..... | 23 29 12 | 18 | *300 | ..... | ..... | |
| | | C..... | 23 38 .. | 18 | ..... | ..... | ..... | |
| | | F..... | 23 57 .. | ..... | ..... | ..... | ..... | |
| 16 | ..... | P..... | 22 44 00 | ..... | ..... | ..... | ..... | |
| | | M..... | 22 55 12 | 17 | *200 | ..... | ..... | |
| | | F..... | 23 14 .. | ..... | ..... | ..... | ..... | |
| 19 | ..... | eP..... | 21 16 36 | ..... | ..... | ..... | ..... | Comparison with records at other stations indicates that P should come a little earlier. |
| | | iS..... | 21 24 6 | 17 | *400 | ..... | ..... | |
| | | L..... | 21 32 42 | ..... | ..... | ..... | ..... | |
| | | M..... | 21 36 30 | 17 | *100 | ..... | ..... | |
| | | C..... | 21 42 .. | 18 | ..... | ..... | ..... | |
| | | F..... | 21 53 .. | 18 | ..... | ..... | ..... | |

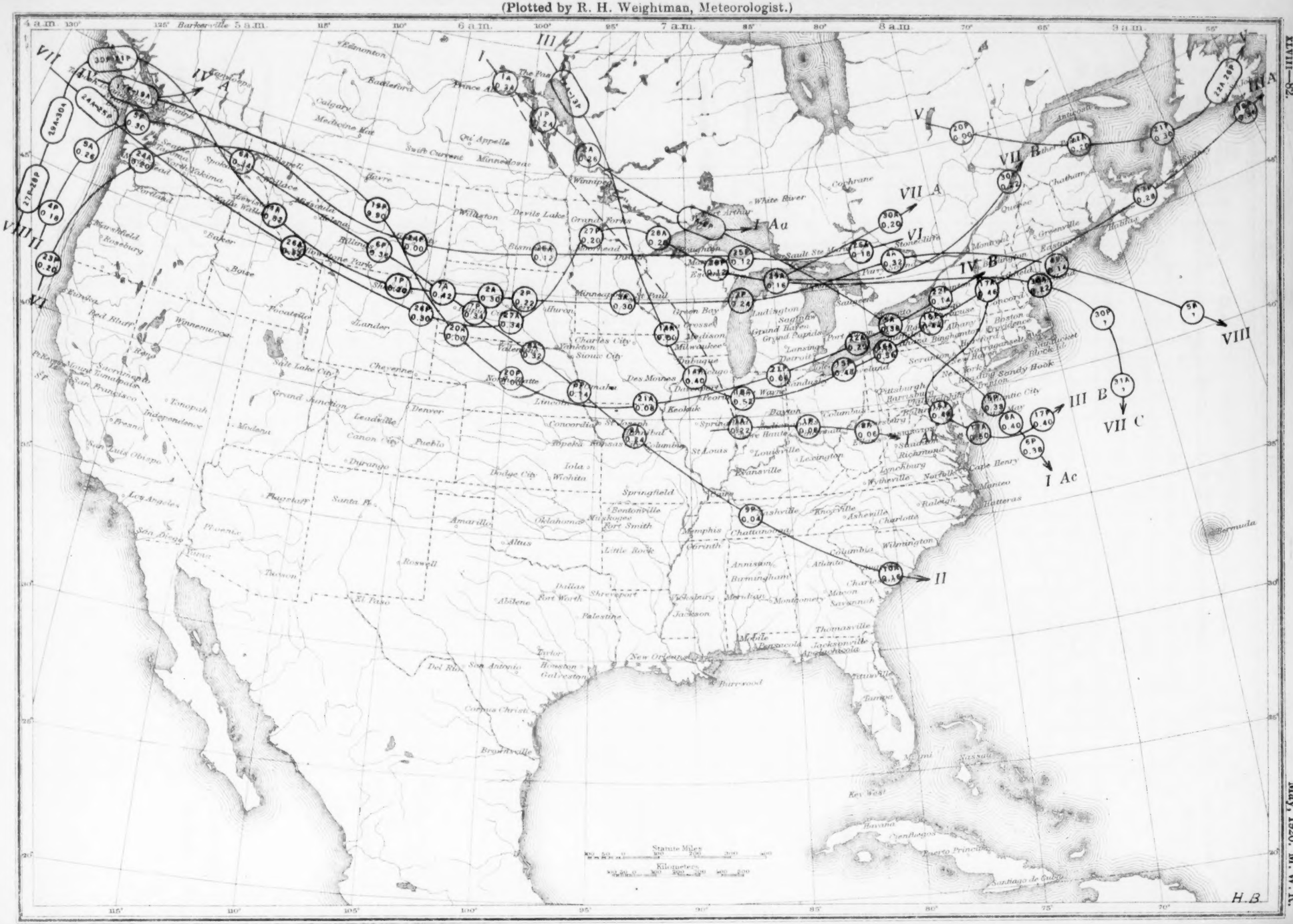
* Trace amplitude.

**Chart I. Hydrographs of Several Principal Rivers, May, 1920.**



## Chart II. Tracks of Centers of High Areas, May, 1920.

(Plotted by R. H. Weightman, Meteorologist.)






## Chart III. Tracks of Centers of Low Areas, May, 1920.

(Plotted by R. H. Weightman, Meteorologist.)

## Chart III. Tracks of Centers of Low Areas, May, 1920.

(Plotted by R. H. Weightman, Meteorologist.)

Chart IV. Departure (°F.) of the Mean Temperature from the Normal, May, 1920.

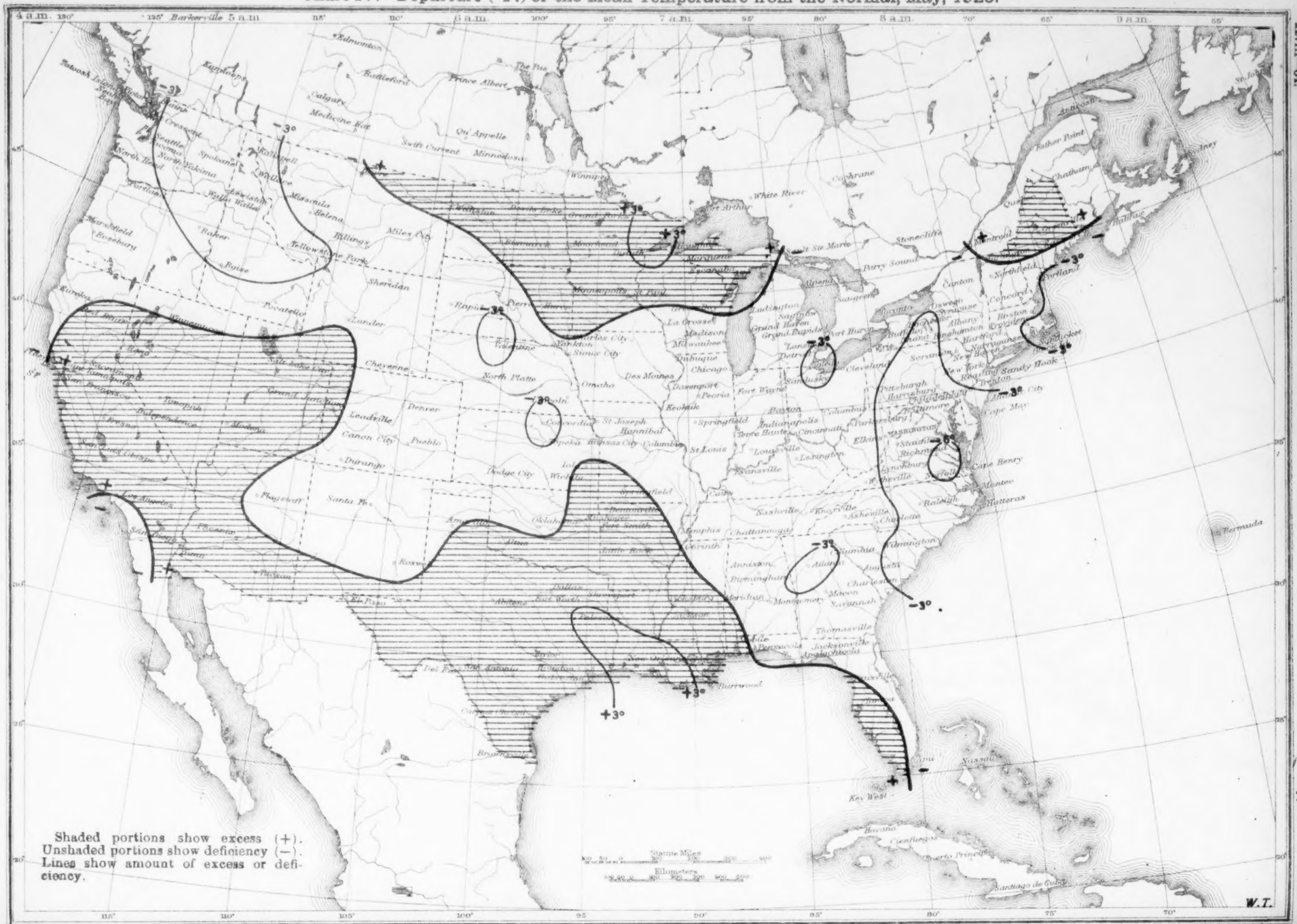
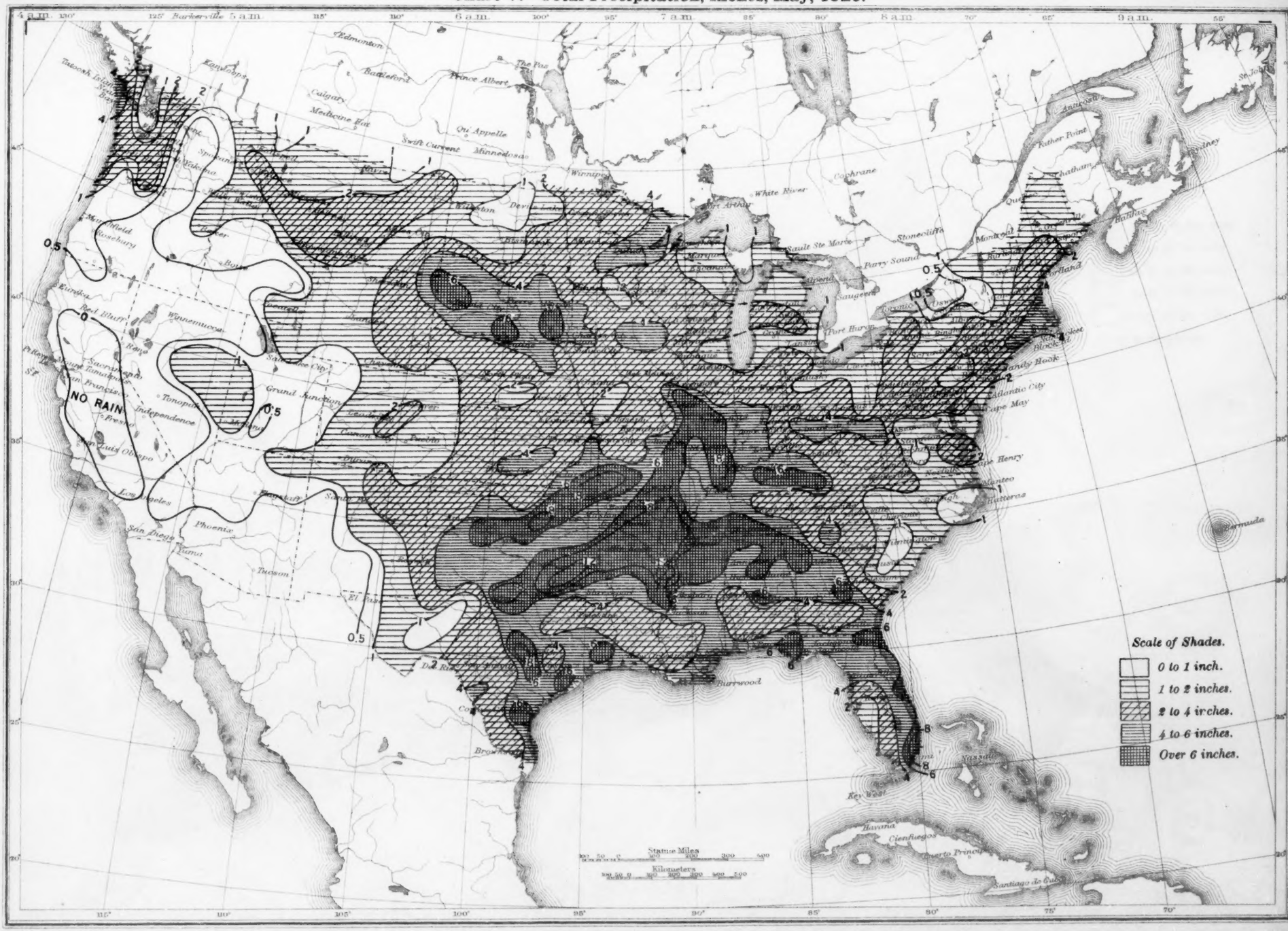


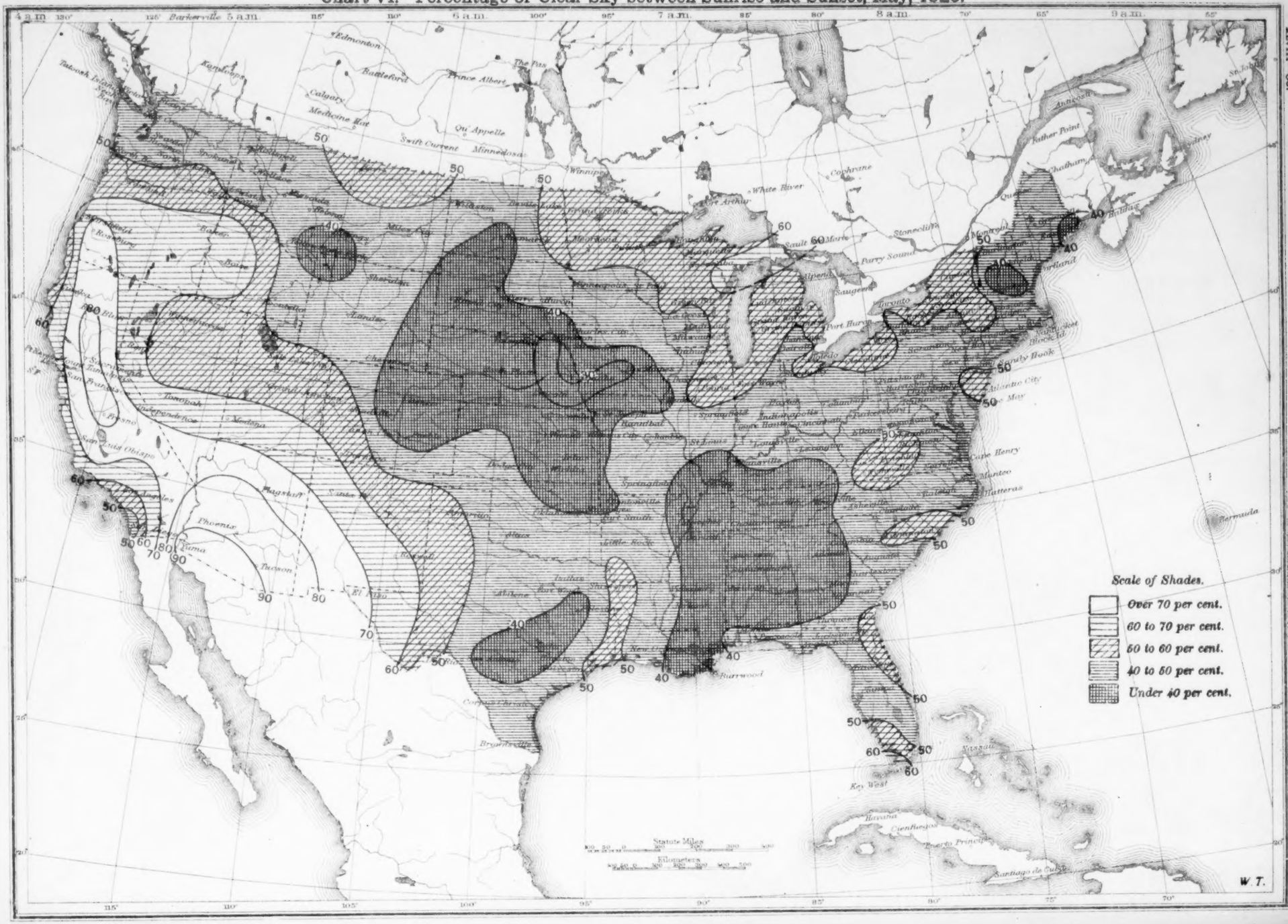



Chart V. Total Precipitation, Inches, May, 1920.

## Chart V. Total Precipitation, Inches, May, 1920.



## Chart VI. Percentage of Clear Sky between Sunrise and Sunset, May, 1920.






## Chart VII. Isobars and Isotherms at Sealevel; Prevailing Winds, May, 1920.

## Chart VII. Isobars and Isotherms at Sealevel; Prevailing Winds, May, 1920.

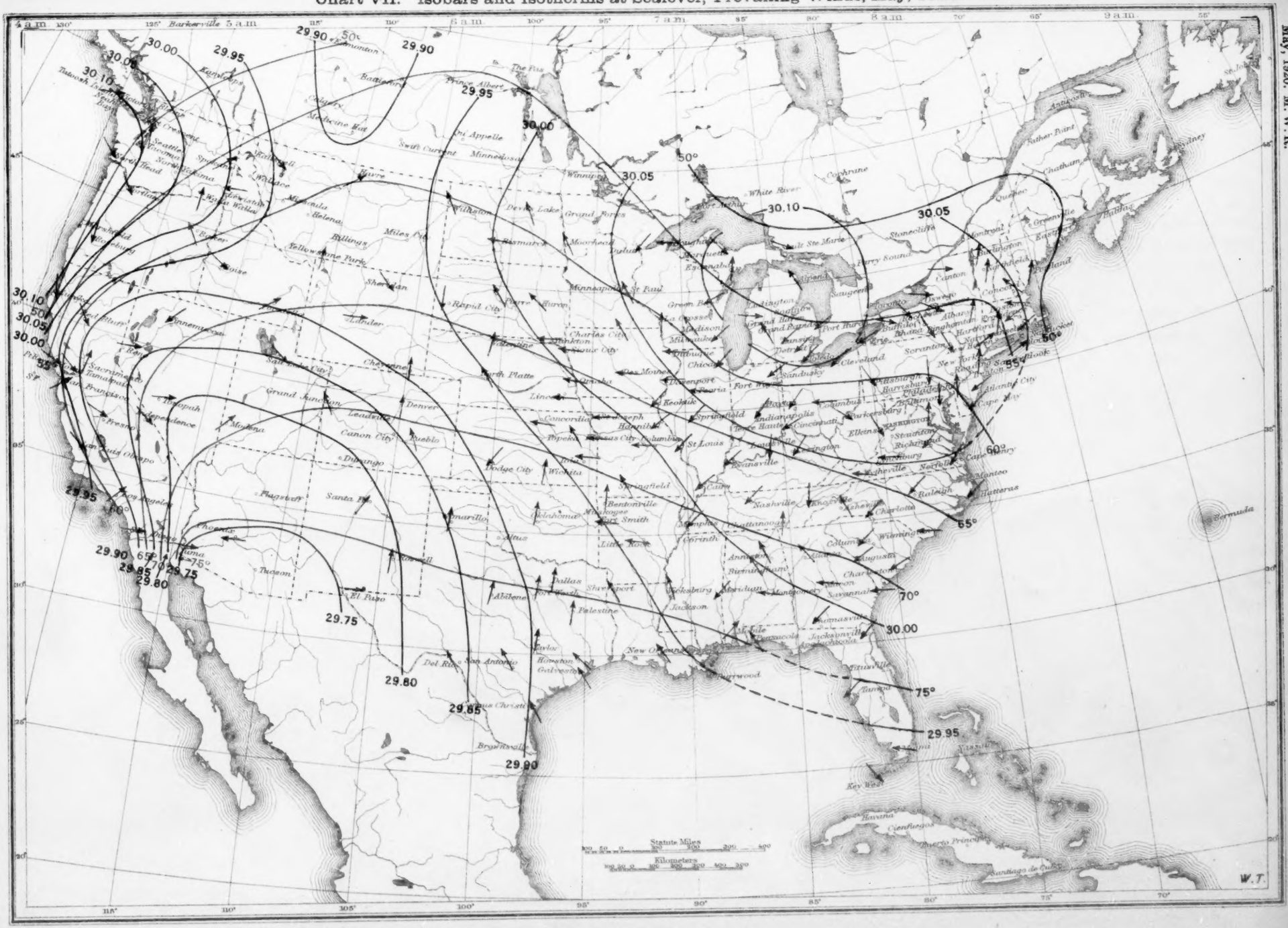


**Chart IX. Weather Map of North Atlantic Ocean, May 2, 1920.**

(Plotted by F. A. Young.)

# Chart IX. Weather Map of North Atlantic Ocean, May 2, 1920.

(Plotted by F. A. Young.)

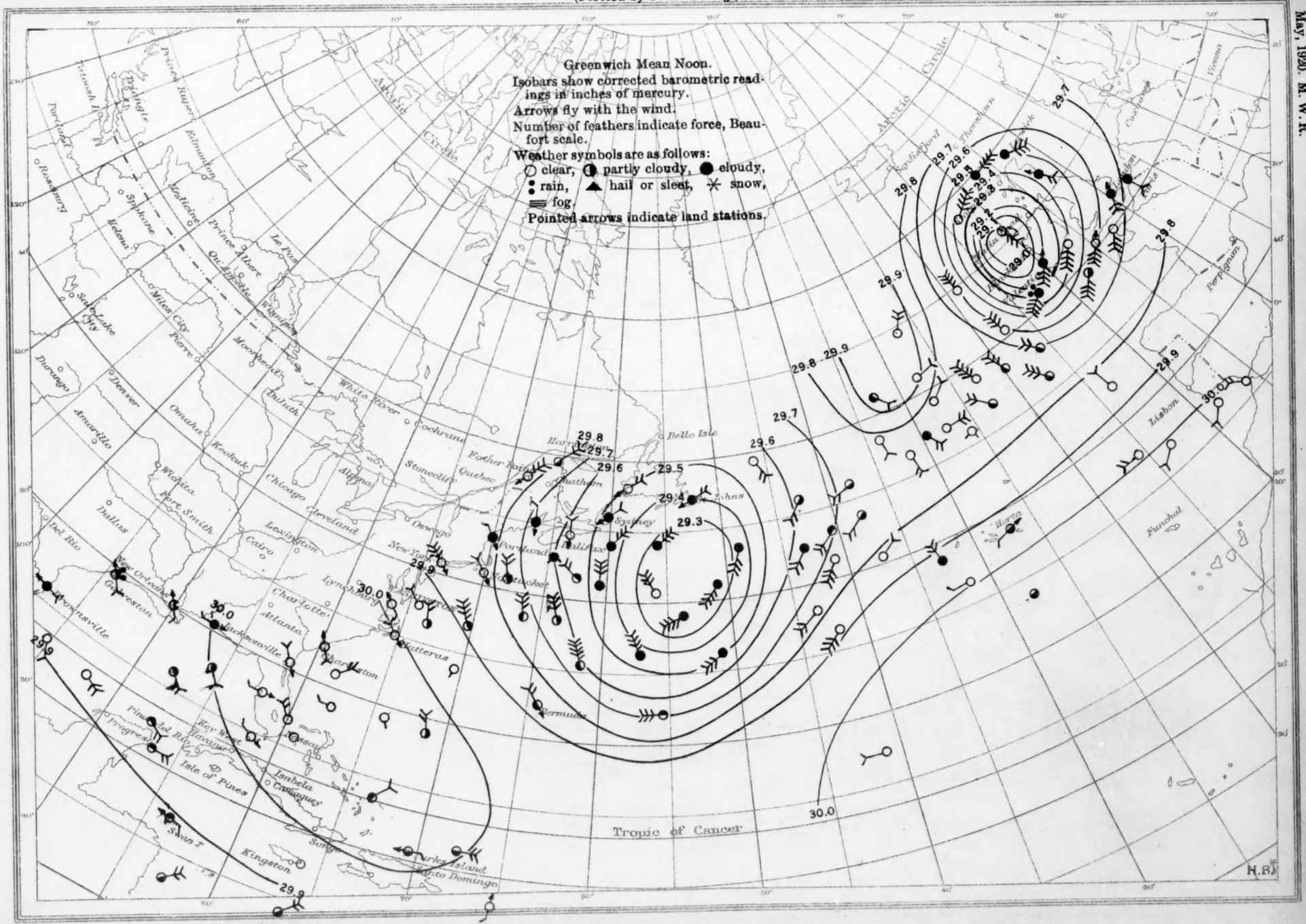


**Chart X.** Weather Map of North Atlantic Ocean, May 3, 1920.

(Plotted by F. A. Young.)

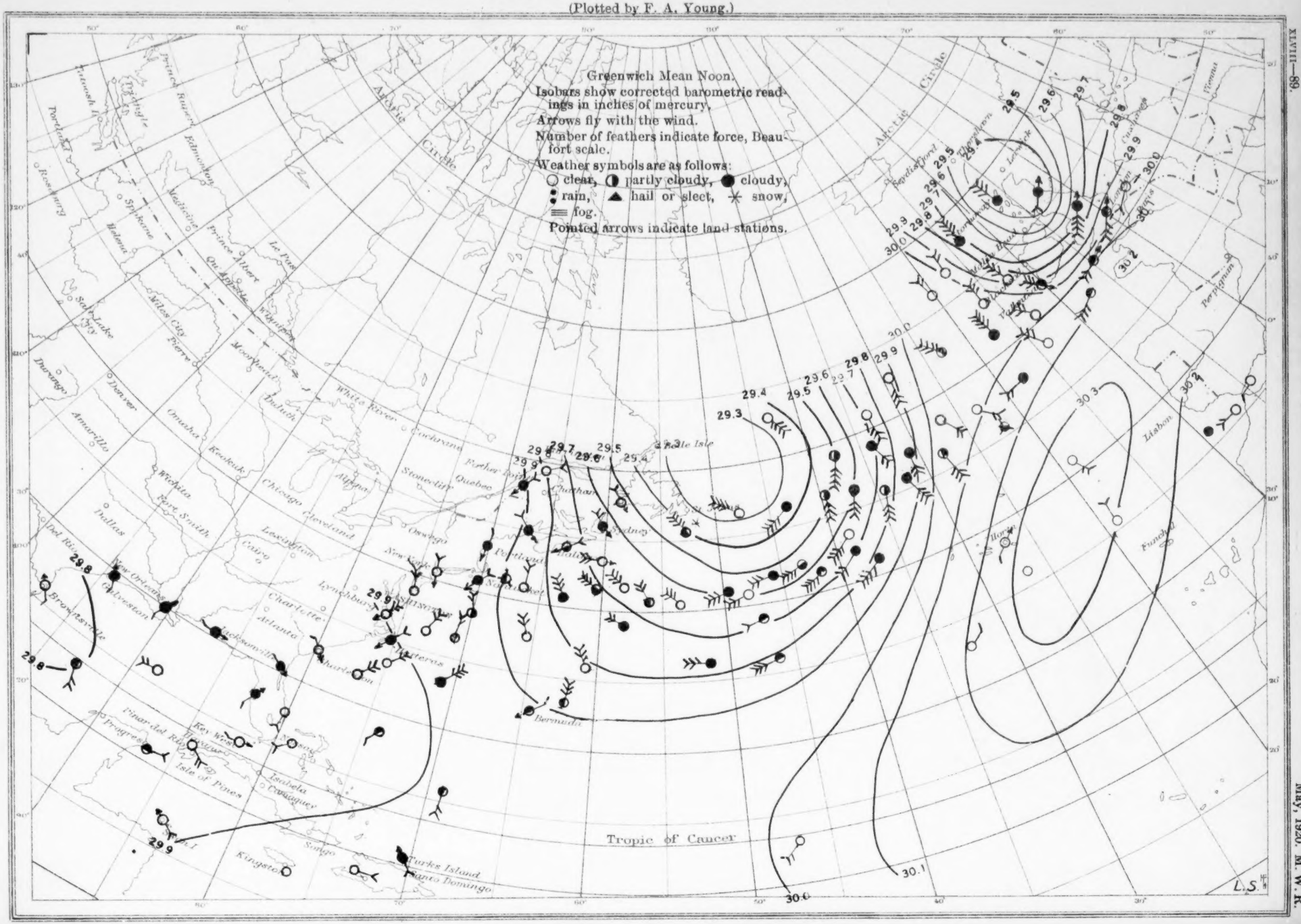
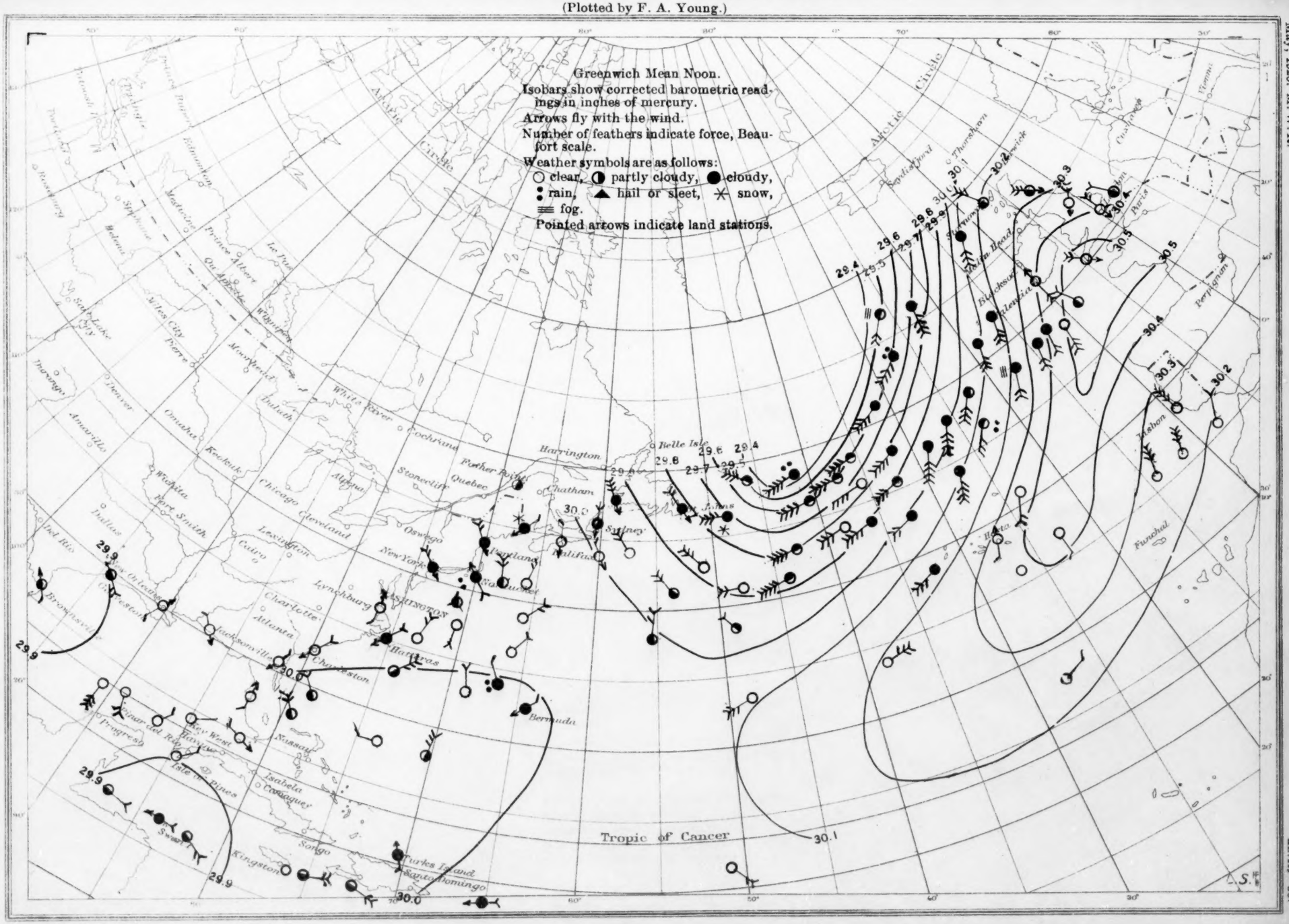

Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail or sleet, snow,
fog.
Pointed arrows indicate land stations.
Arctic Circle
Tropic of Cancer
L.S.



**Chart XI.** Weather Map of North Atlantic Ocean, May 4, 1920.

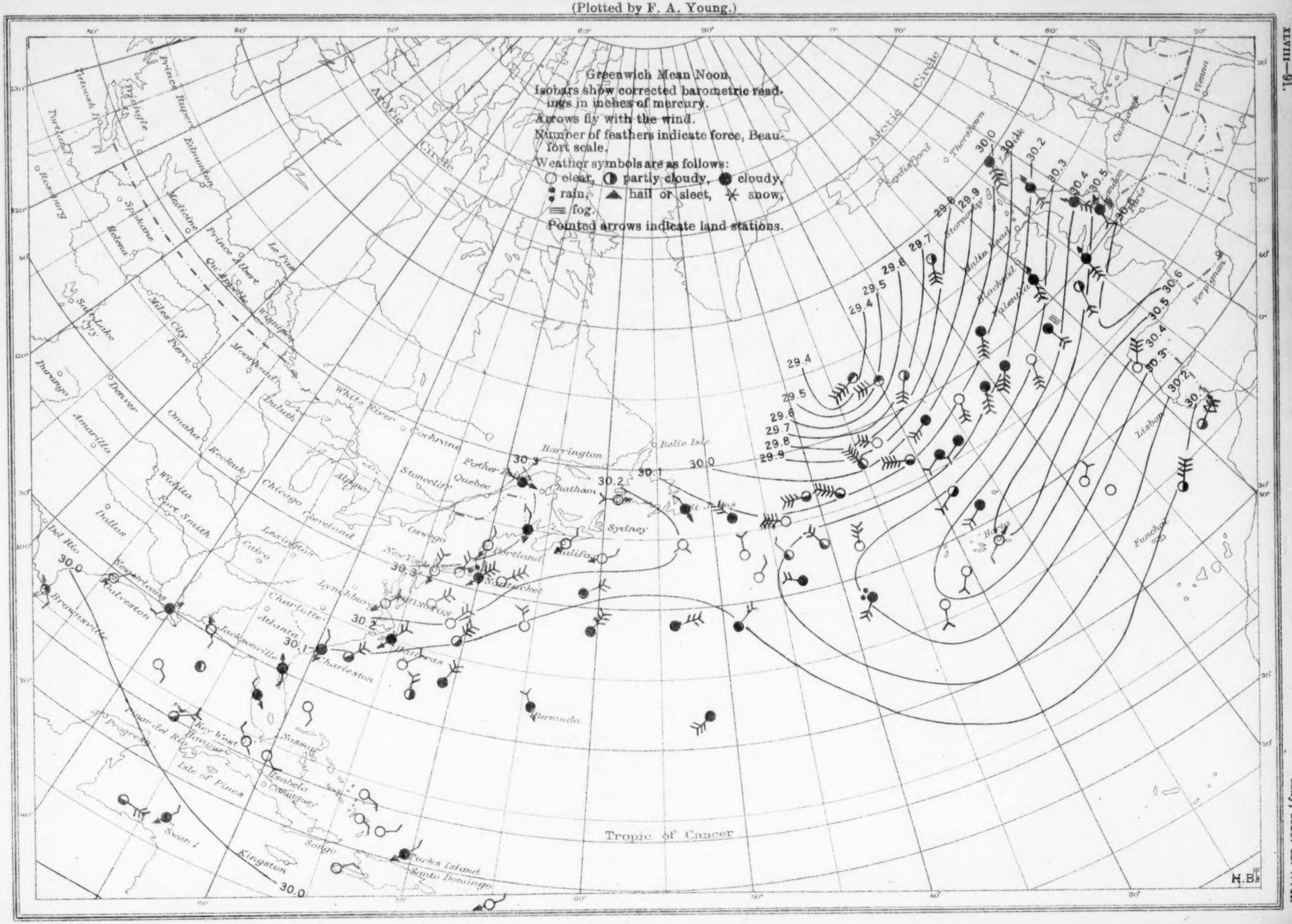
## Chart XI. Weather Map of North Atlantic Ocean, May 4, 1920.

(Plotted by F. A. Young.)


Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail or sleet, snow,
fog.
Pointed arrows indicate land stations.
Tropic of Cancer
Arctic Circle
Harrington
Belle Isle
Father Point
Quebec
Chatham
Sydney
Halifax
Bermuda
Nassau
Turks Island
Santo Domingo
Kingston
Key West
Tampa
Charleston
Hatteras
Jacksonville
Atlanta
Charlotte
Lynchburg
Washington
New York
Portland
Oswego
Buffalo
Cleveland
Chicago
Omaha
Duluth
White River
Cochrane
Stonecliffe
Alpena
Rockford
Dodge City
Amarillo
Denver
Pierre
Winnipeg
Prince Albert
Battleford
Edmonton
Medicine Hat
Swift Current
Moose Jaw
Qu'Appelle
Prince Albert
Battleford
Edmonton
Medicine Hat
Swift Current
Moose Jaw
Qu'Appelle
Winnipeg
Pierre
Dodge City
Amarillo
Denver
Omaha
Duluth
White River
Cochrane
Stonecliffe
Alpena
Rockford
Chicago
Cleveland
Oswego
New York
Portland
Buffalo
Halifax
Sydney
Belle Isle
Harrington
Father Point
Quebec
Chatham

## Chart XII. Weather Map of North Atlantic Ocean, May 5, 1920.

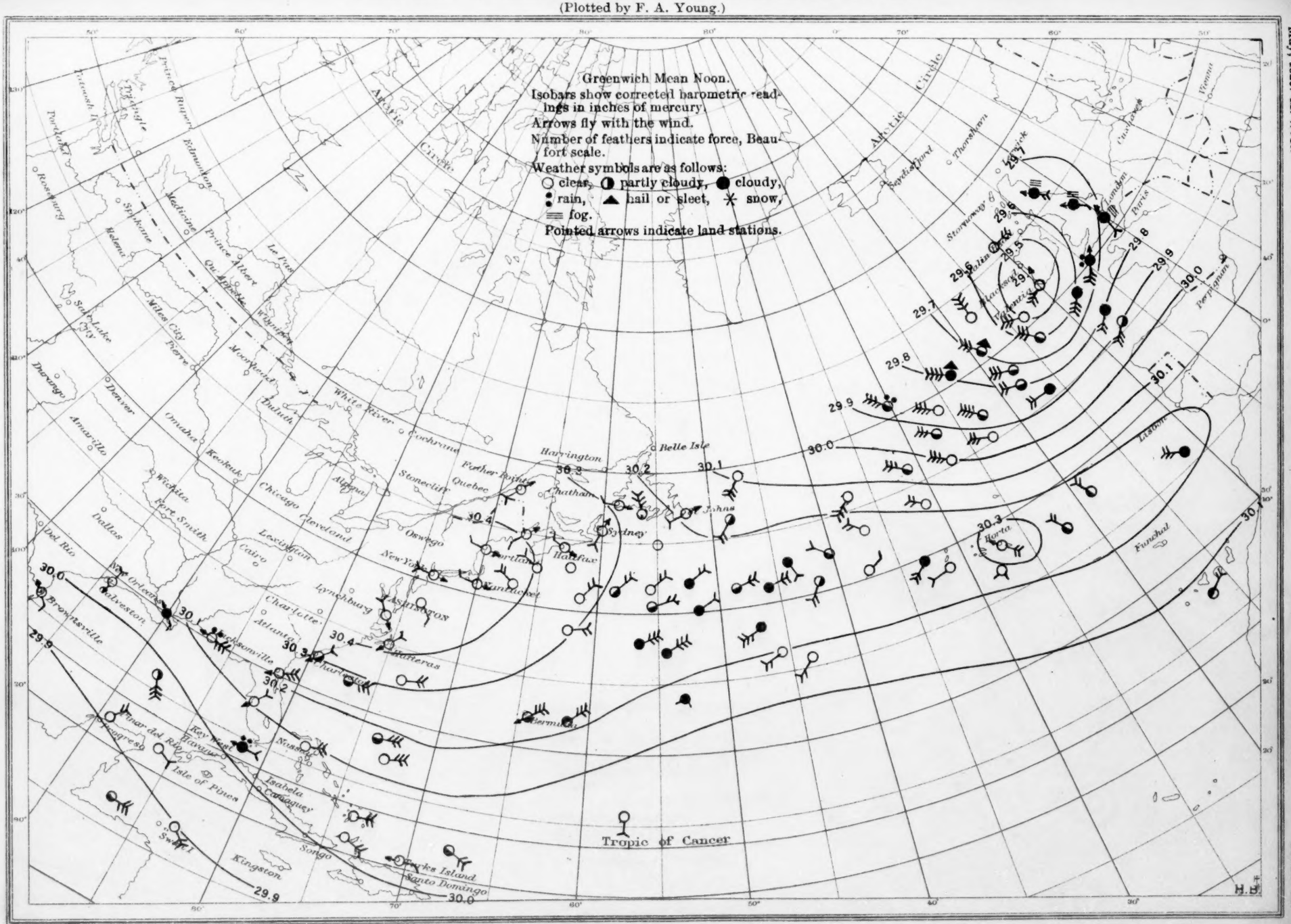
(Plotted by F. A. Young.)


Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind.
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail or sleet, snow,
fog.
Pointed arrows indicate land stations.
Arctic Circle
Tropic of Cancer
H.B.

## Chart XIII. Weather Map of North Atlantic Ocean, May 17, 1920.

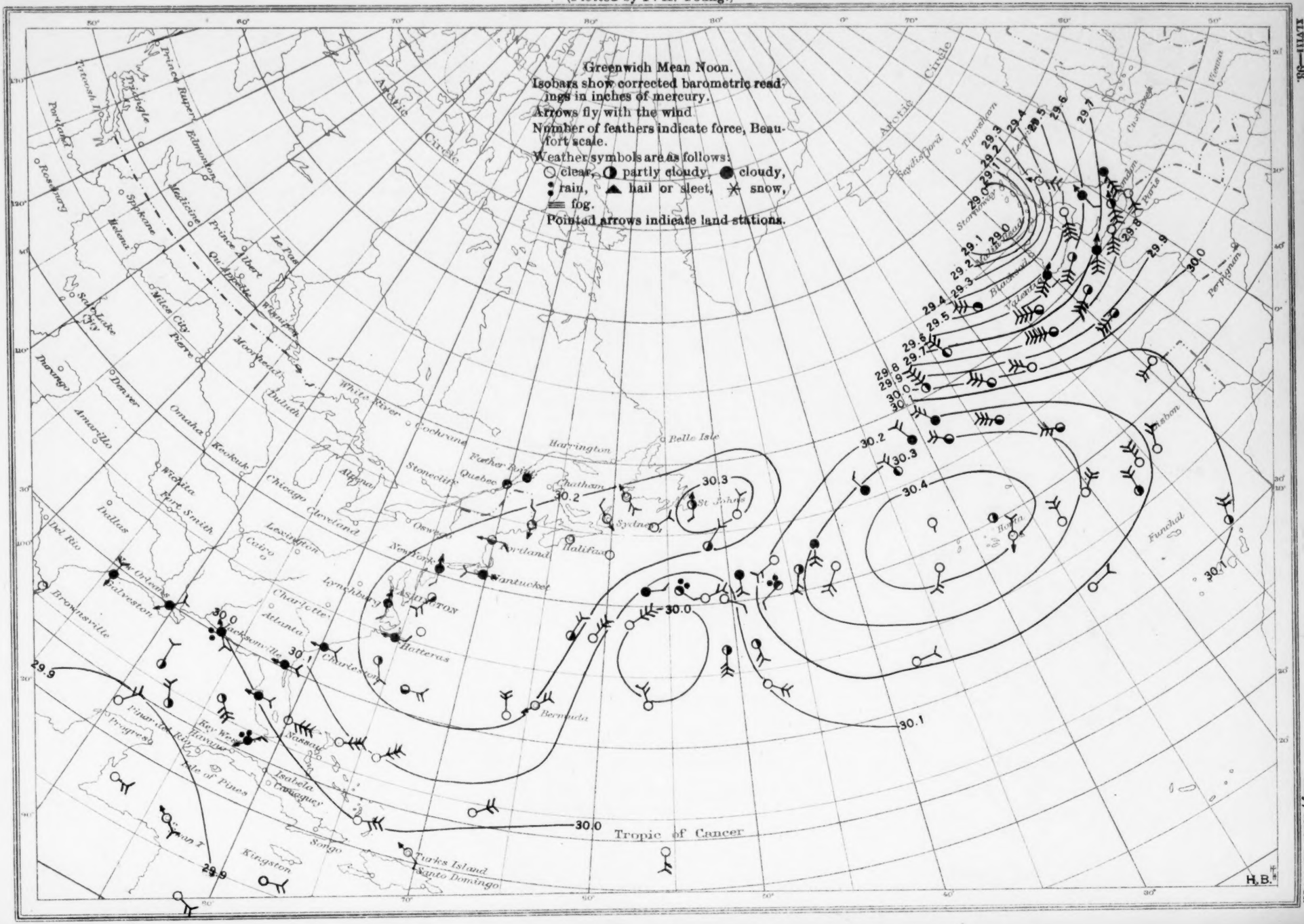
## Chart XIII. Weather Map of North Atlantic Ocean, May 17, 1920.

(Plotted by F. A. Young.)



# Chart XIV. Weather Map of North Atlantic Ocean, May 18, 1920.

(Plotted by F. A. Young.)


Greenwich Mean Noon.
Isobars show corrected barometric readings in inches of mercury.
Arrows fly with the wind
Number of feathers indicate force, Beaufort scale.
Weather symbols are as follows:
clear, partly cloudy, cloudy,
rain, hail or sleet, snow,
fog.
Pointed arrows indicate land stations.
Arctic Circle
Tropic of Cancer
H.B.